Acoustic Fundamentals

SOUND PROPAGATION

Classification

UNCLASSIFIED

Objectives

- Identify units used in ASW and their inter-conversions
- Identify the effects of temperature, pressure and salinity on sound propagation.
- Identify governing principles associated with sound propagation to include Wilson’s Equation and Snell’s Law.

Objectives

- Identify aspects of ocean structure to include primary energy source, three layer model and variation.
- Identify sound propagation paths to include: direct path, surface duct, bottom bounce, sound channel convergence zone.
- Identify terms associated with and factors that affect sound propagation paths.

References

- **Fleet Oceanographic and Acoustic Reference Manual (RP-33)**
- **Operational Oceanography - Acoustics and Sound Ray Theory (METOC 60-1T-9602)**
- **Environmental Effects of Weapon Systems and Naval Warfare (RP-1)**
- **Tactical Use of the Ocean Environment (NWP 3-59.1)**
- **Submarine Sonar Environmental Manual (SP-140)**
- **Surface Shp Acoustic Prediction Systems and Tactics (NWP 3-21.34)**

Speed VS Velocity

Speed VS Velocity

Answer:

- Speed – Scalar = magnitude only
  - Other scalars – mass, distance, volume, time, work and power
- Velocity – Vector = magnitude + direction
  - Other vectors – displacement, acceleration, force

Units

- Units provide the background for the math and physics behind tactical oceanography.

- DON'T FEAR THEM! Understanding units and their interrelation helps you to accurately define your environment, your target, and yourself in useful terms.

Units cont.

- Changes - Where □ = (final – initial)
  - Depth - □ Z
  - Sound Velocity - □ C
- Pressure – atmospheres, bars, pounds per square inch, kilograms per square centimeter
- Distance – nautical mile, statue mile, kilometer

Question: Which is longer, a nautical mile, kilometer or statue mile?

- Statue mile – 5280 feet or 1.6093 kilometers
- Nautical mile – 6076.2 feet or 1.853 km
- Kilometer – 3279.98 feet or .621 miles

Conversions

- Depth
  - 1 meter = 3.2808 feet
  - 1 fathom = 6 feet = 1.829 meters
- Temperature
  - F to C = 5/9*(Temp in F) – 17.778
  - C to F = 9/5*(Temp in C) + 32

Conversions Cont.

- Pressure
  - 1 atmosphere = 14.696 lbs/sq inch
  - 1 bar = 1000 mb = .9869 atm
    - Standard atmosphere? 1013.27 mb
  - Rule of thumb: 1 atm every 33 ft/10 m of depth

Units Used in ASW

- Sound “Speed” (velocity) – ft/sec or m/sec
- Depth – ft/fathoms/meters
- Temperature – degrees Celsius or Fahrenheit
- Salinity – parts/thousand, 0/00, Practical Salinity units or just unitless

Importance of Sound

Why use sound?

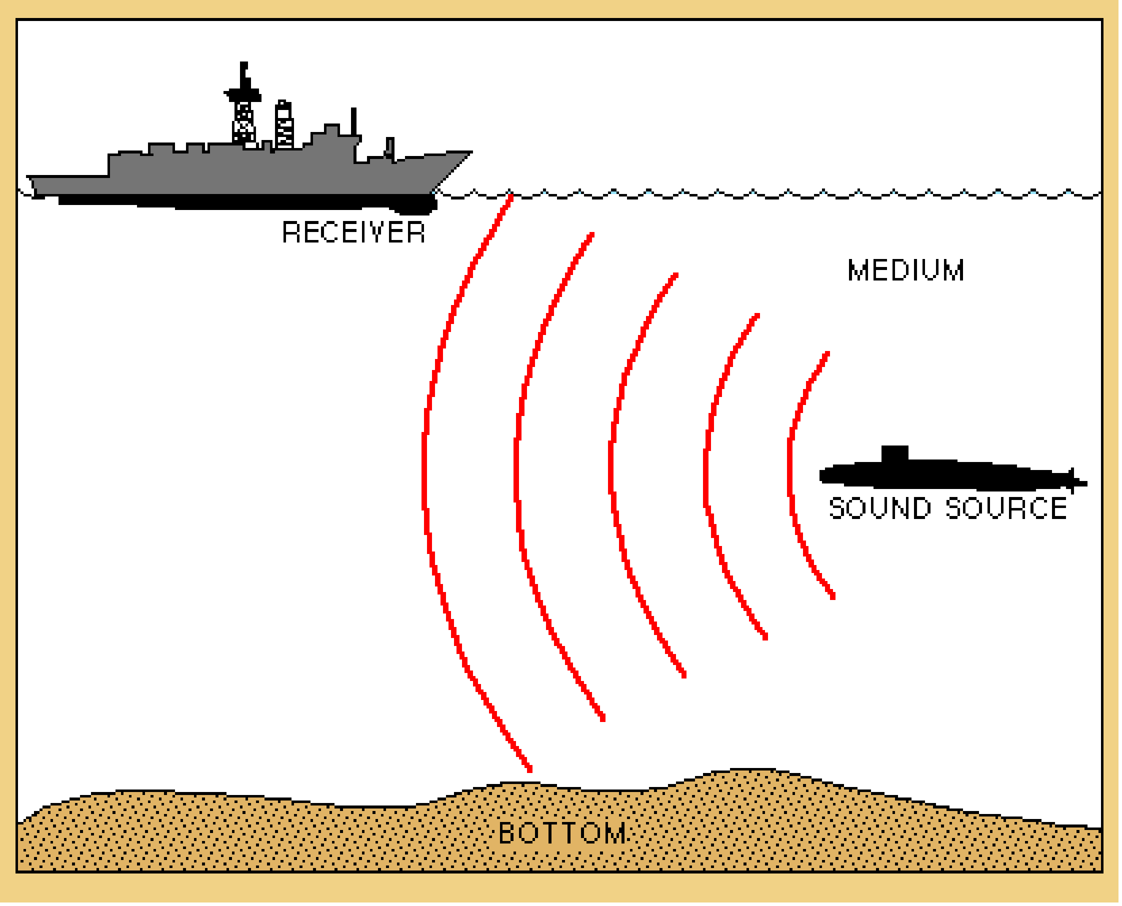
- Only tactically exploitable energy source that can penetrate water for any distance

Components

Source

Receiver

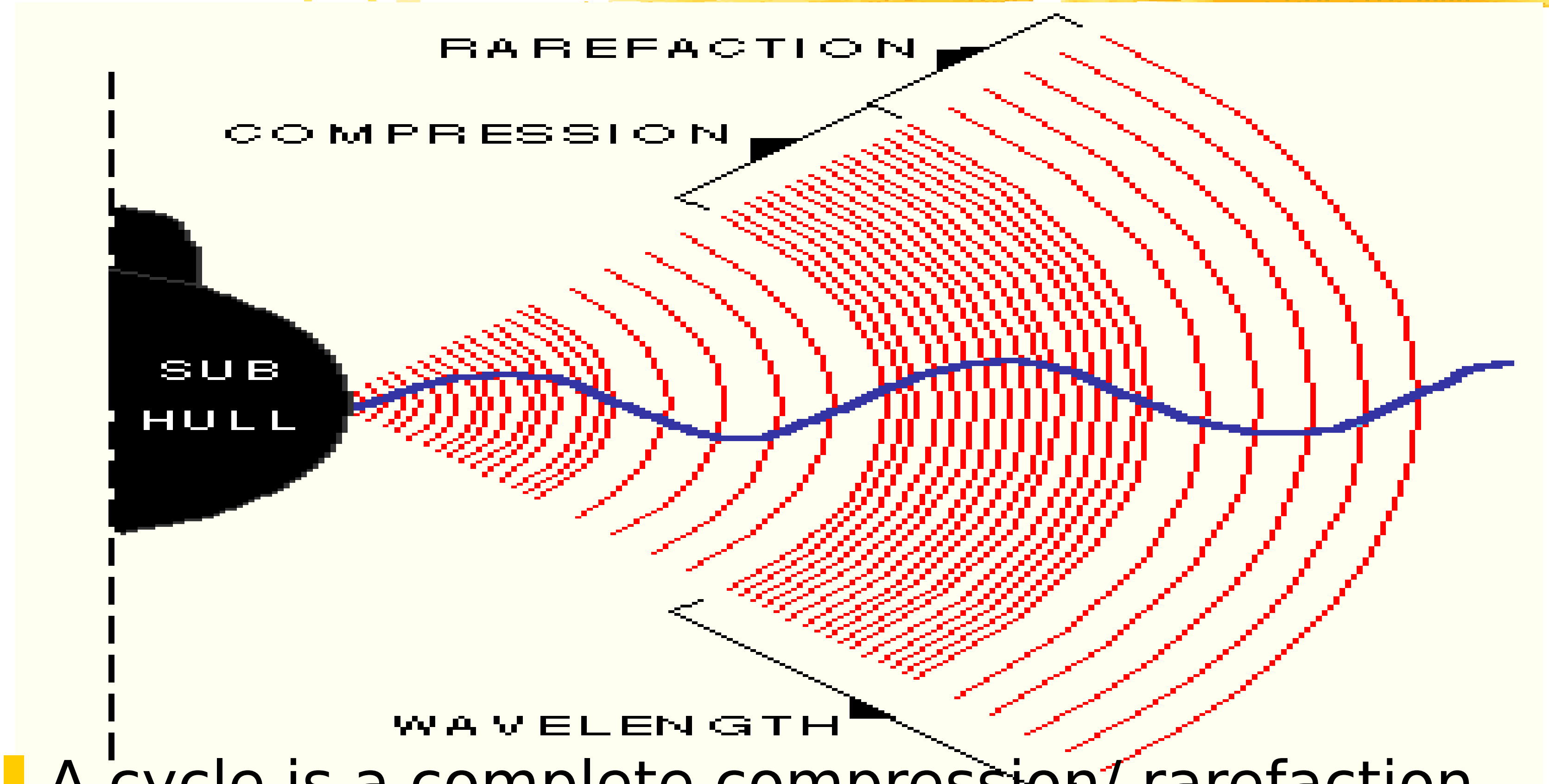
Medium



Wave Fundamentals

- Underwater sound is an alteration of pressure as it propagates through water in a series of mechanical compression waves.

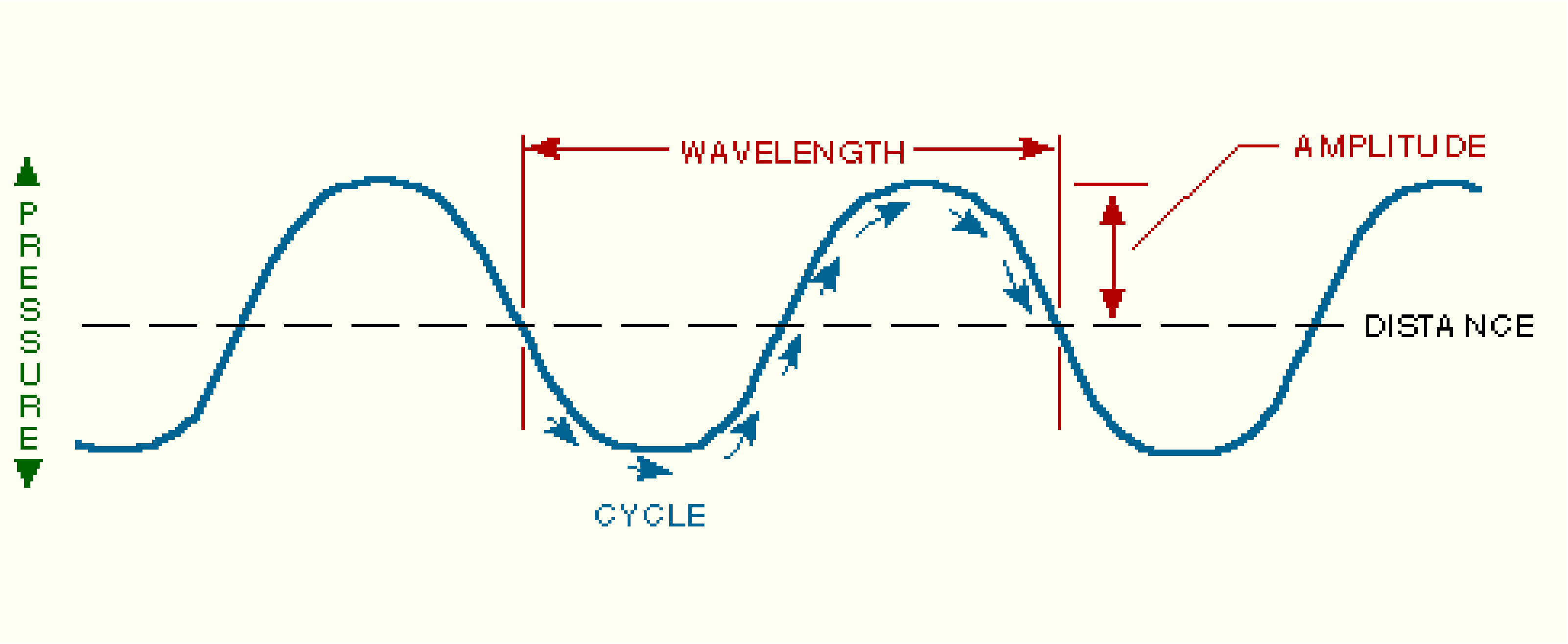
Wave Fundamentals



- A cycle is a complete compression/ rarefaction.

Wave Fundamentals

- Wavelength is the distance a wave travels in one complete cycle.
- Amplitude is the magnitude of the wave peaks above or below the reference.



Wave Fundamentals

- Frequency is measured in Hertz (Hz), where 1 Hz equals one cycle per second.

- Wavelength, frequency, and sound speed are related as follows:

Sound Speed = Frequency X Wavelength

Wave Fundamentals

If speed remains constant and frequency decreases, what happens to wavelength?

- Wavelength increases.

Importance of Sound Speed

- Determines propagation characterist

- Basic input for range prediction met

Sound Speed Equation

- Wilson's Equation:

$$C = 1449.2 + 4.623t - 0.0546t^2 + 1.391(S - 35) + 0.017d$$

- where:
  - C = sound speed (m/sec)
  - d = depth (m)
  - t = temperature (·C)
  - S = salinity in parts per thousand (ppt)

Temperature

- Temperature is the measure of kinetic energy (the energy of motion) of molecules.
- Dominant variable affecting sound speed in first few thousand feet of ocean.
- Sound speed increases 4 to 8 ft/sec for each degree F increase.

Salinity

- The amount of dissolved solids and salt in seawater.

- Sound speed increases with salinity at a rate of approximately 4 ft/sec per ppt.

- Effects of salinity in open ocean are usually slight.

Salinity

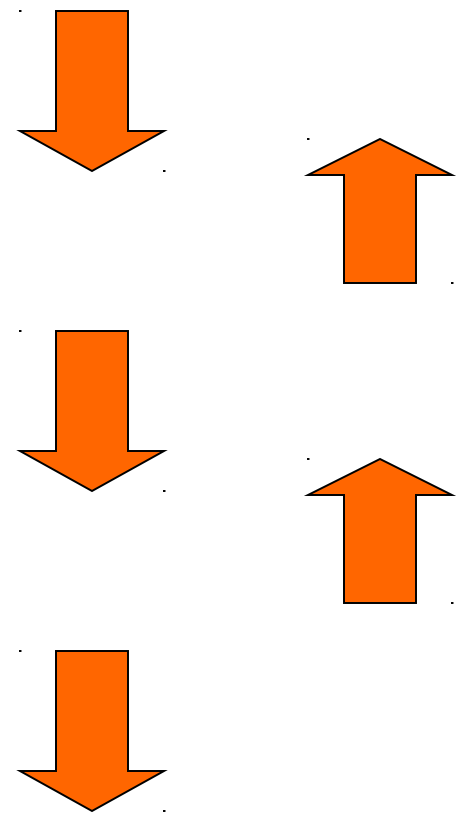
Rainfall

Ice formation

River runoff

Evaporation

Ice melt



Salinity

- Salinity affects water density, enabling some unusual temperature structures to remain stable.

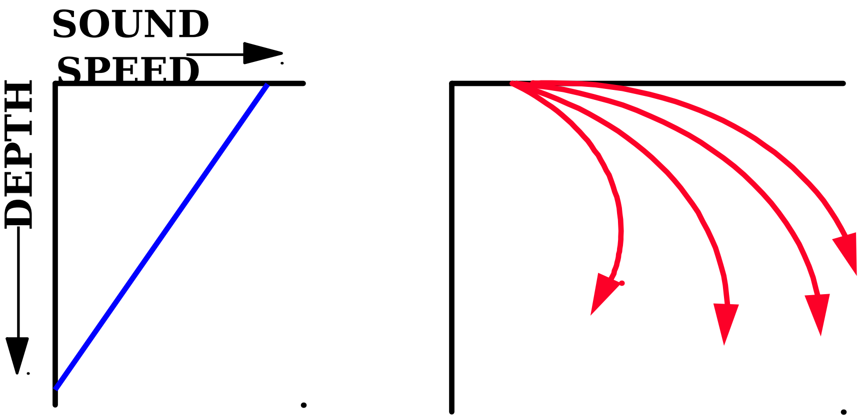
Cool - Fresh

Warm - Salty

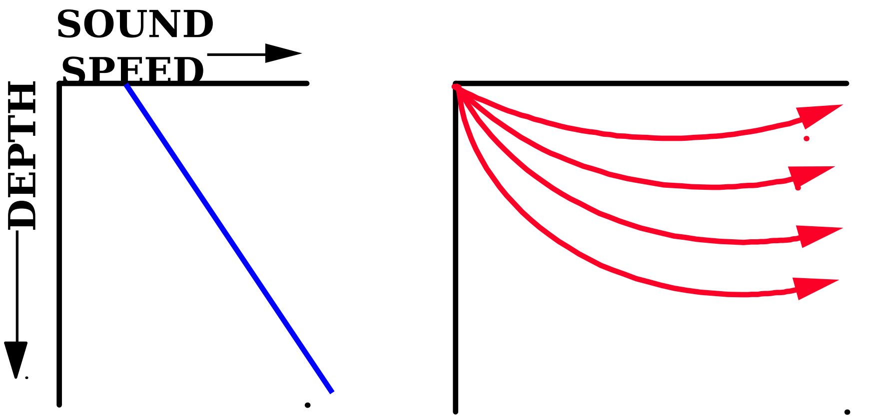
Pressure

- Sound speed increases with increasing depth at a rate of 1.7 ft/sec per 100 ft.
- Most important in deeper parts of ocean where temperature and salinity are virtually constant.
- Independent of season, latitude, time of day.

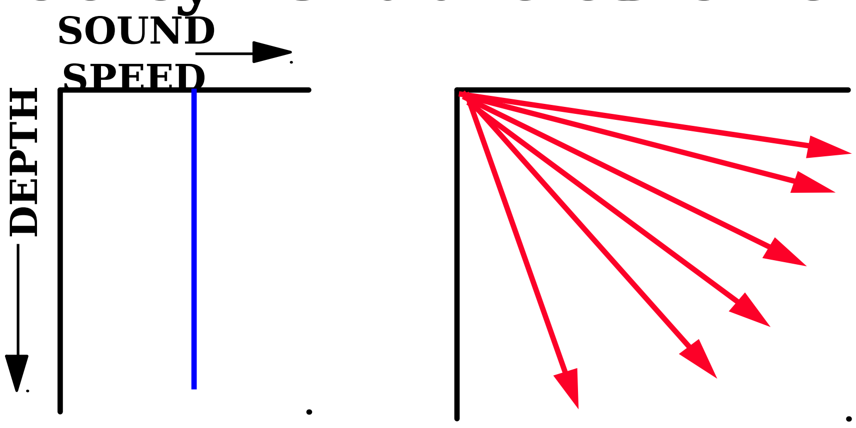
Sound Speed Gradients



Negative Velocity Gradient



Positive Velocity Grad



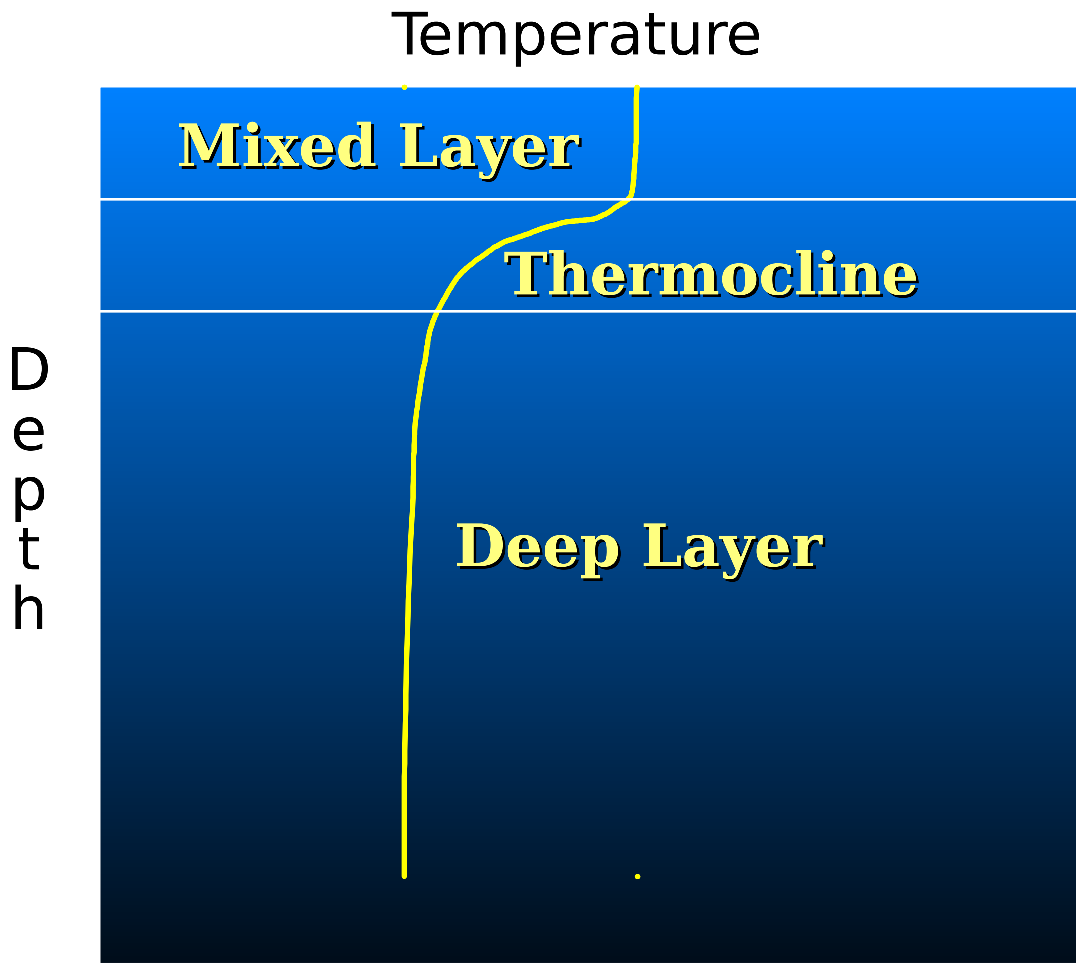
Isovelocity Gradient

Ocean Thermal Structure

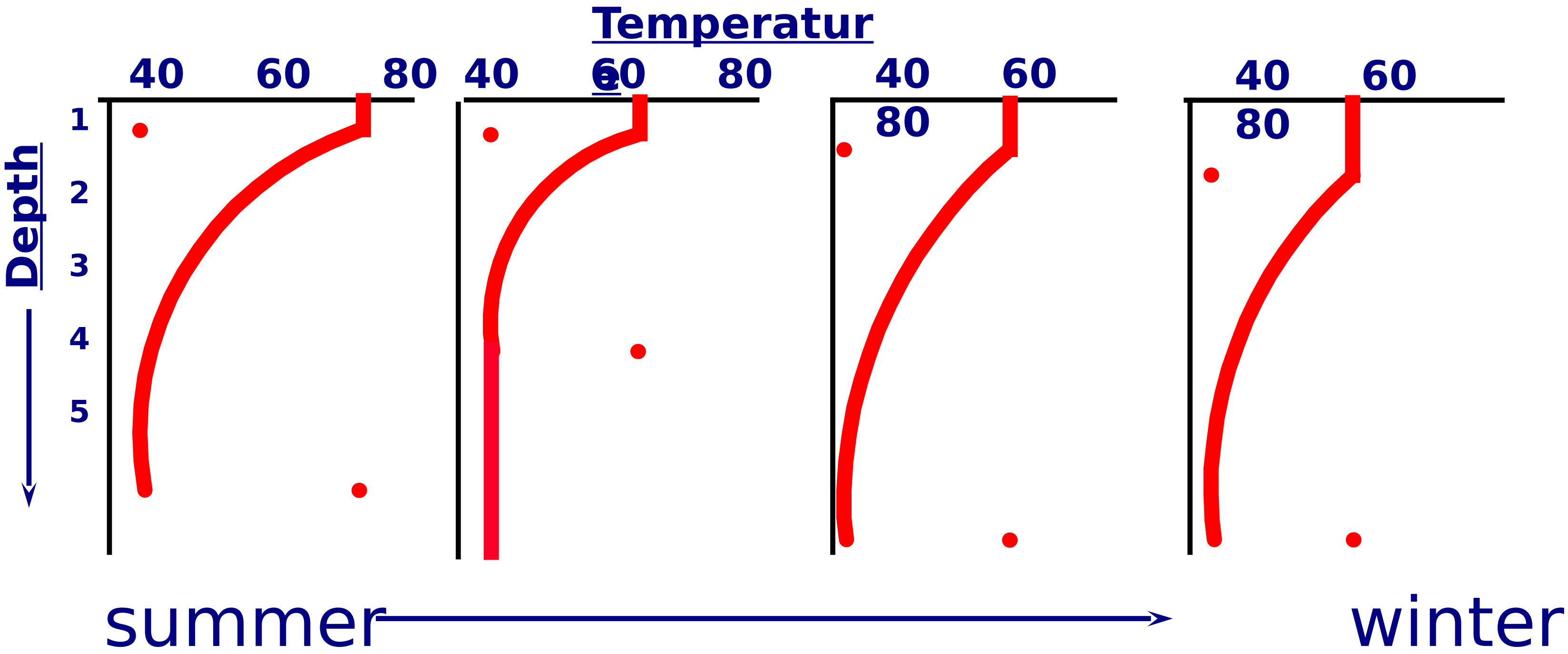
Source - solar radiation

- About 62 percent of radiated heat is absorbed in the first 3 feet of water.
- Mechanical mixing through wave action is primary means of heat transfer.
  - Mechanical mixing is restricted to a few hundred feet - leading to a stratified ocean structure.

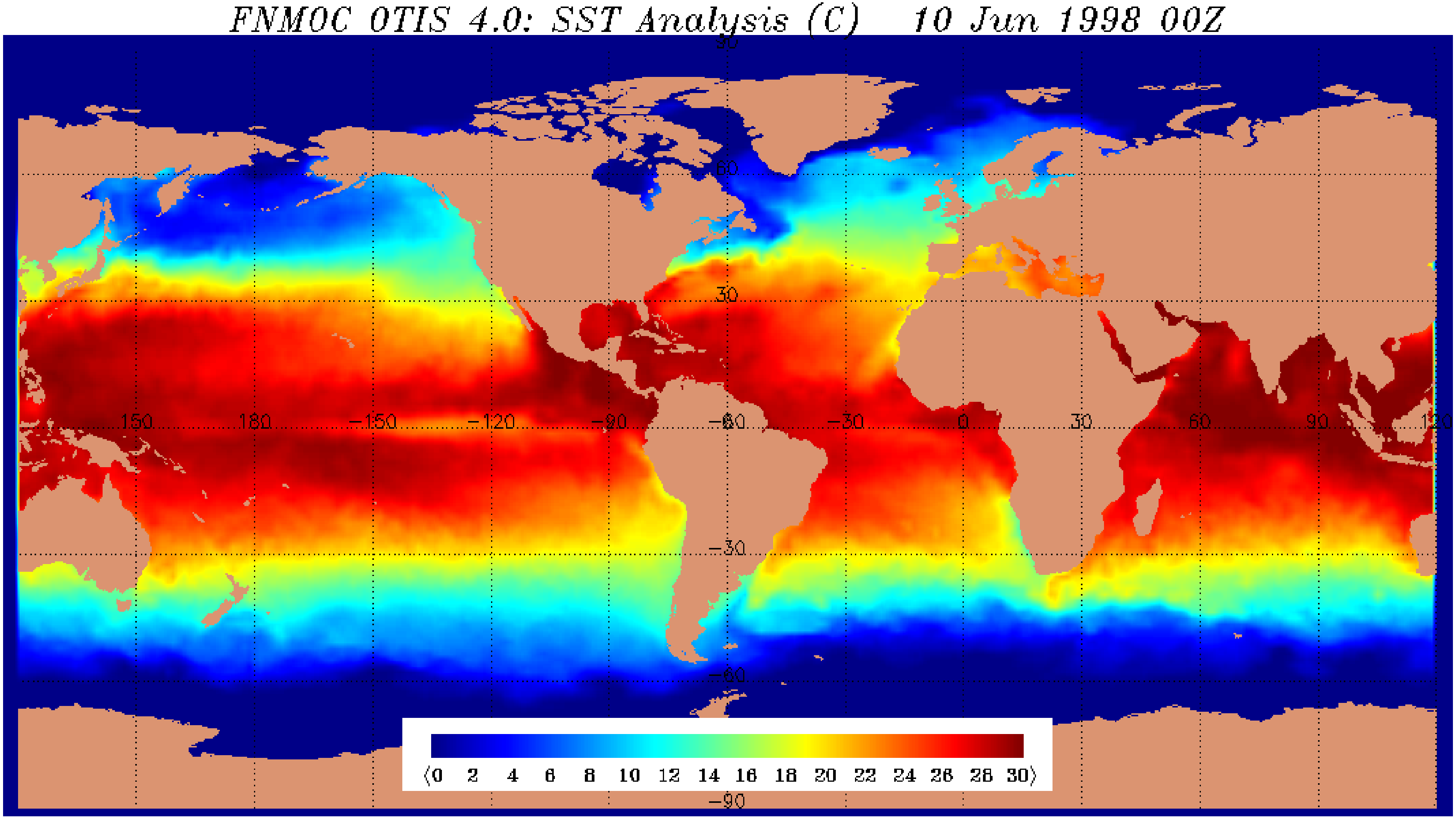
Three-layer Ocean



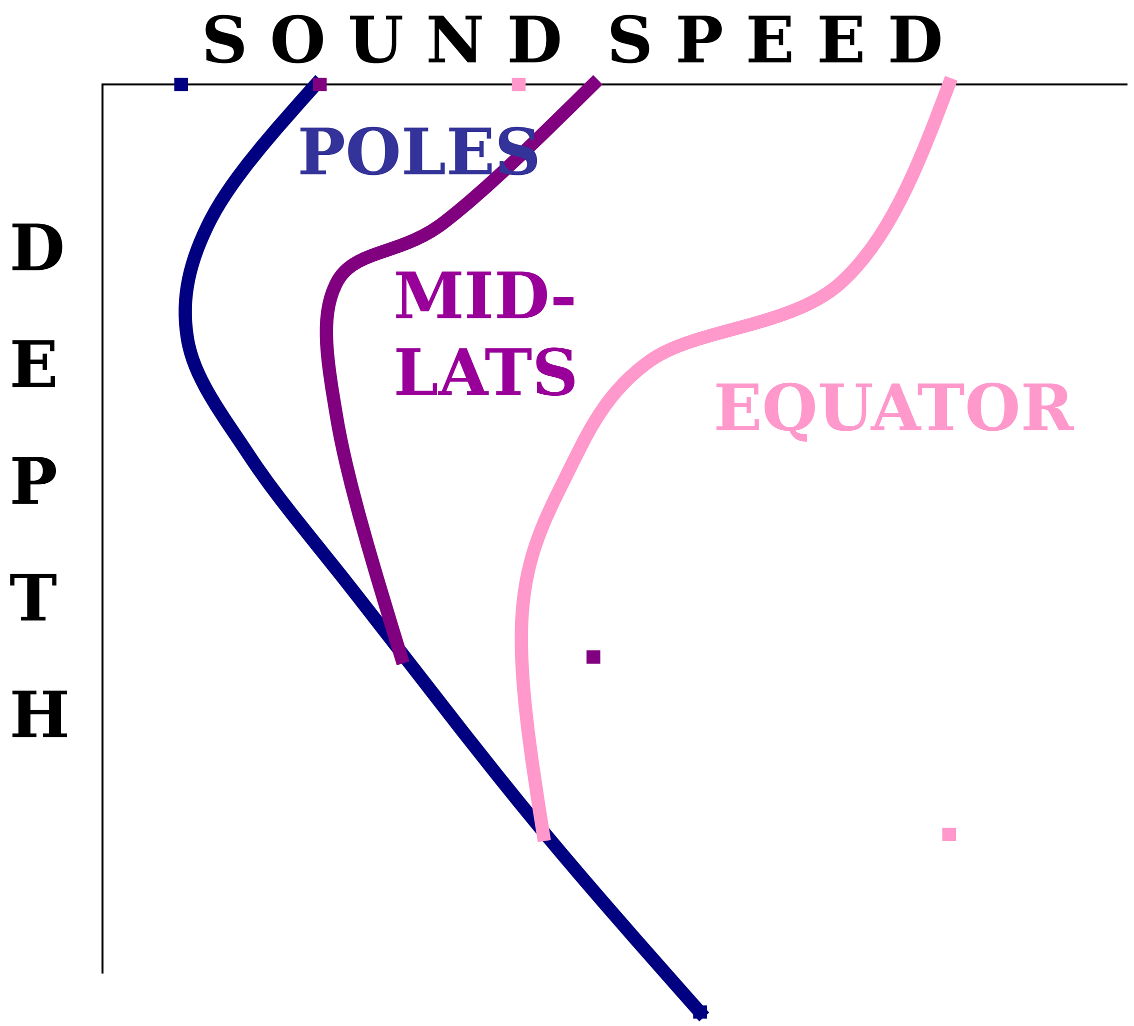
Variation - Seasonal



Variation - Latitudinal

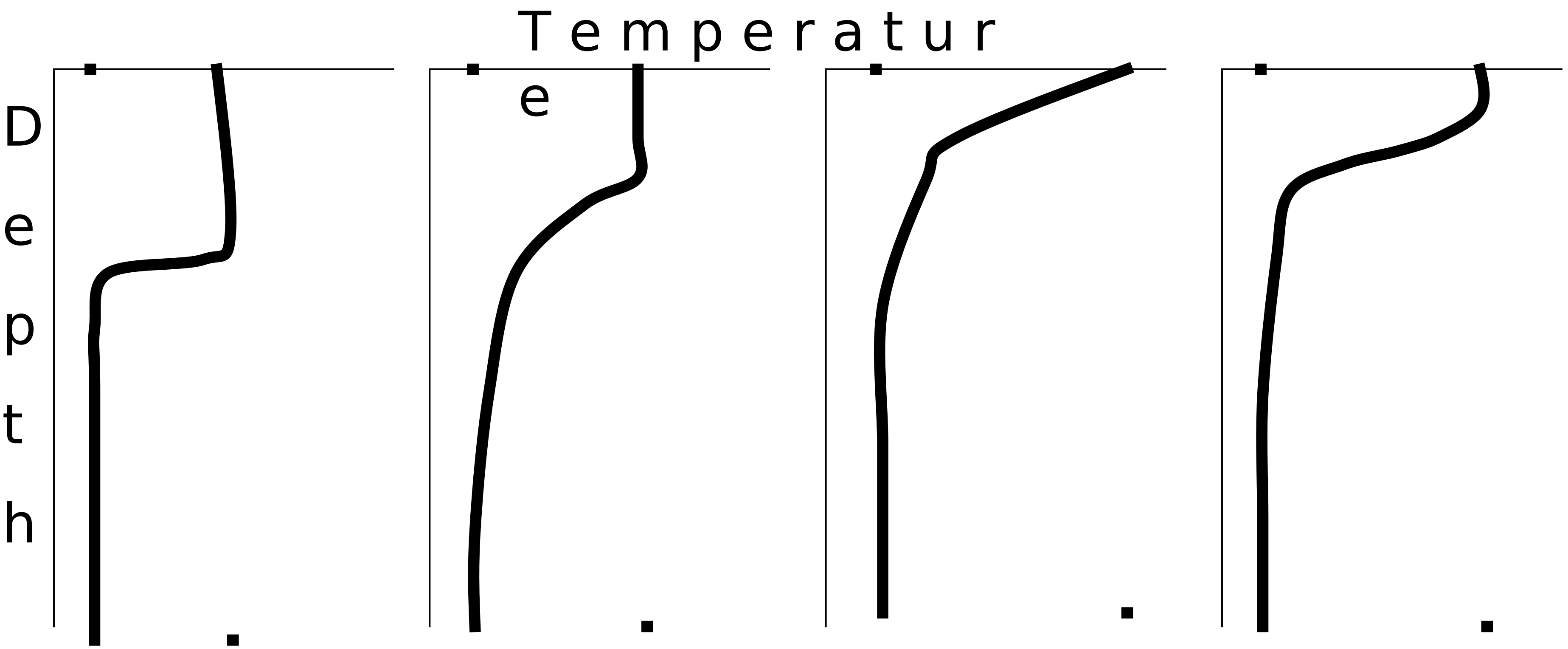


Variation - Latitudinal



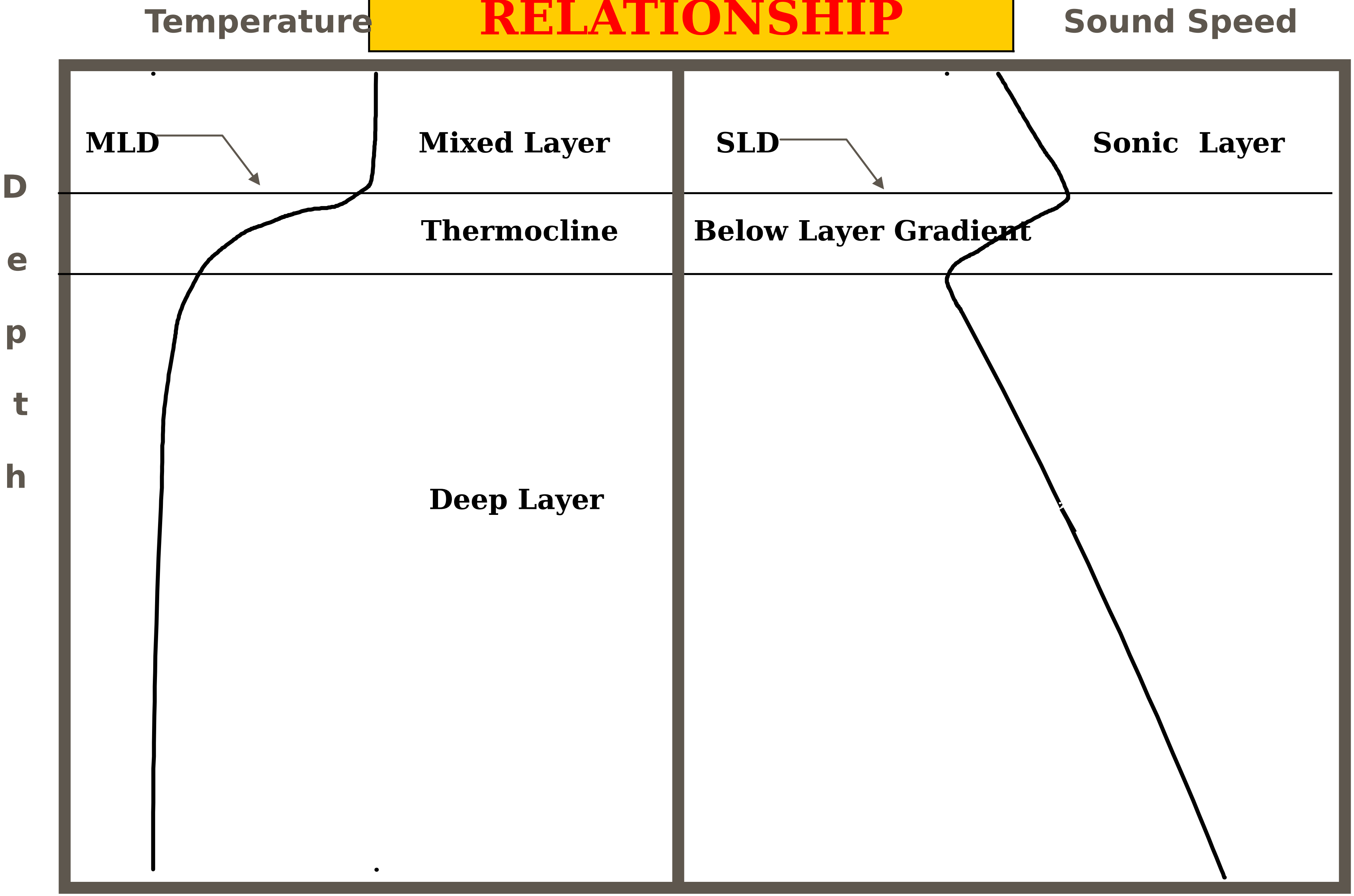
Variation - Diurnal

0600 1000 1400 0200

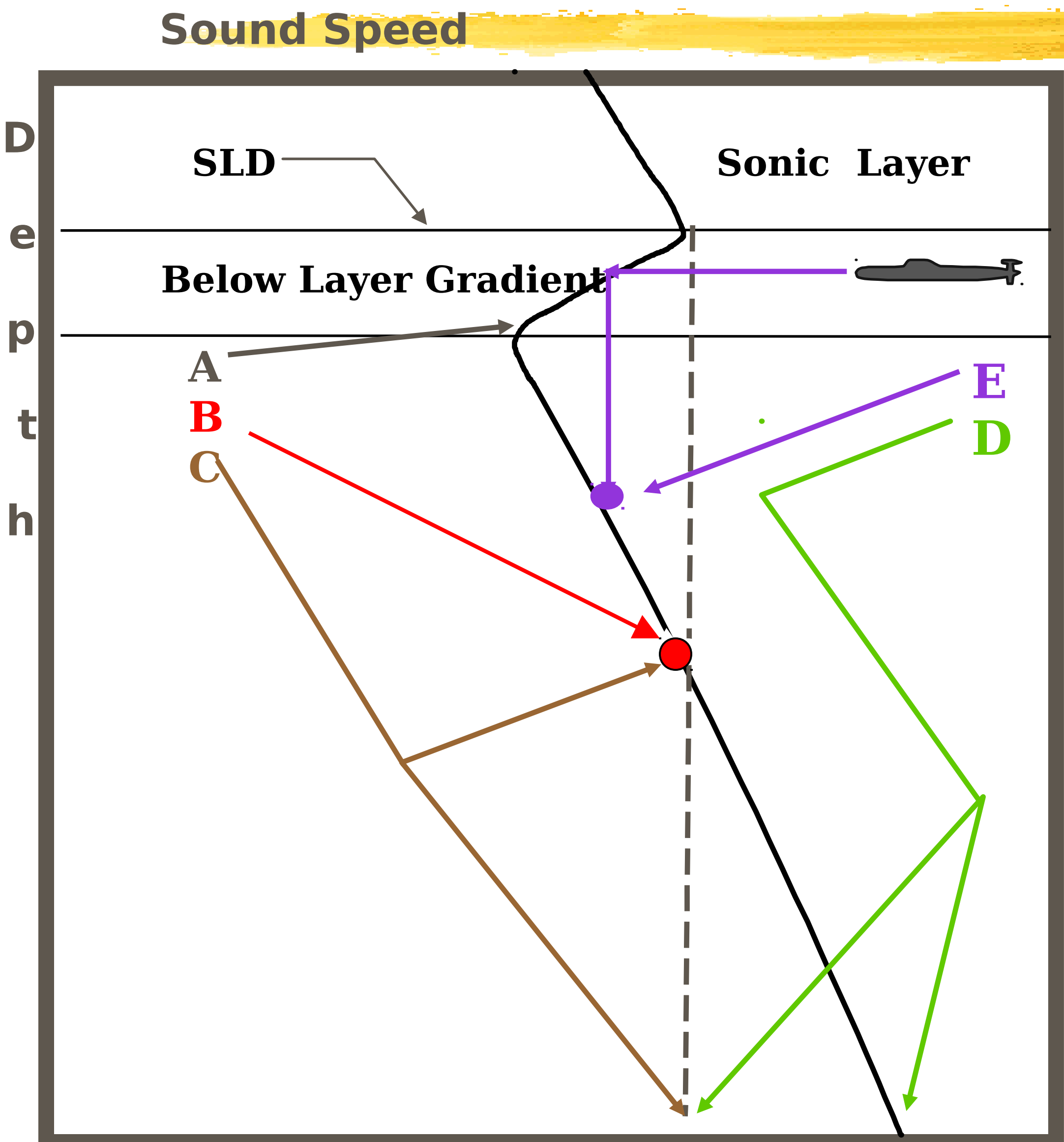


Afternoon Effect

XBT/SSP RELATIONSHIP



SSP Terminology



A - Deep Sound Channel Axis

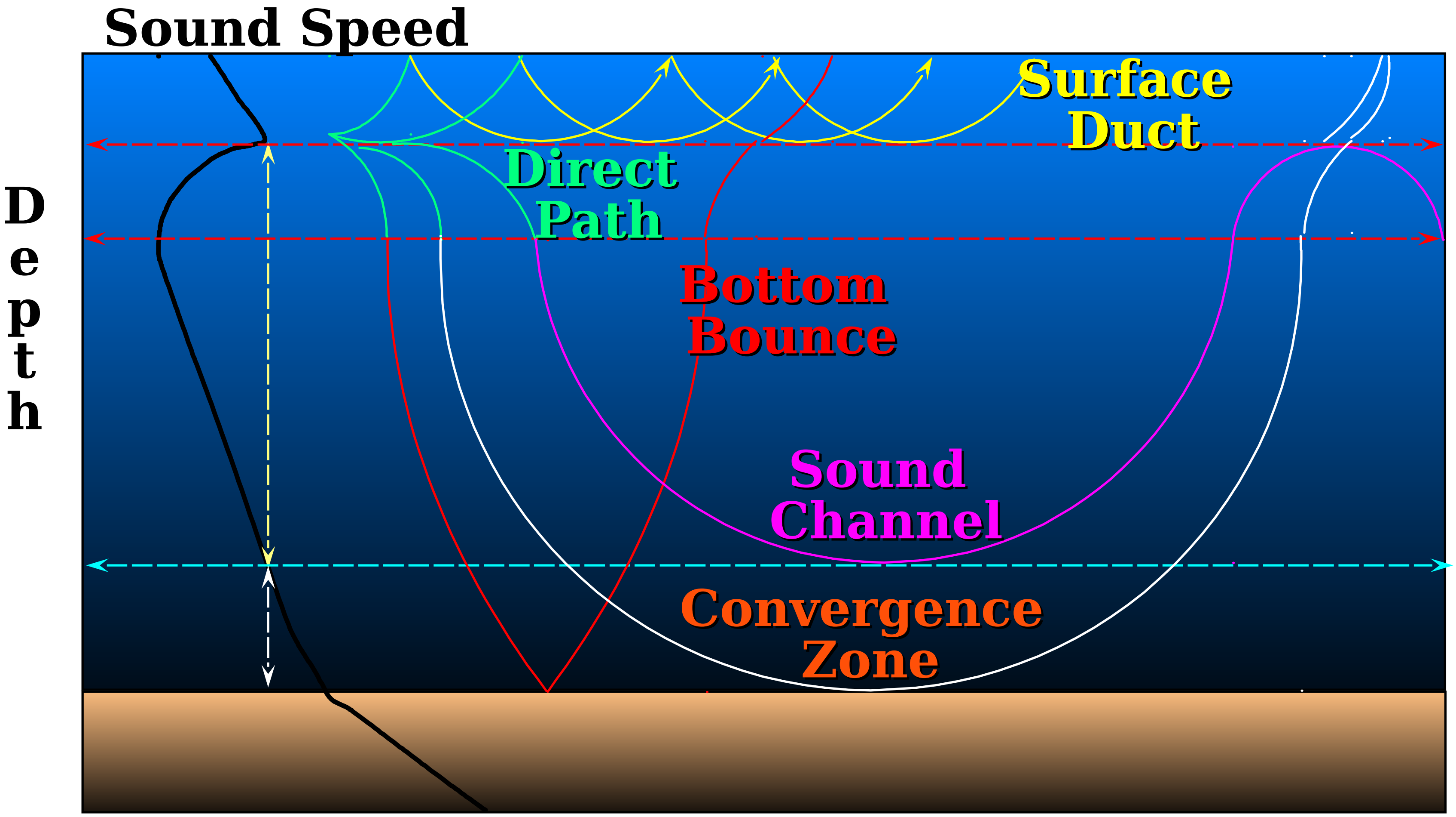
B - Critical Depth

C - Depth Excess

D - Sound Speed Excess

E - Conjugate Depth

Sound Propagation Paths



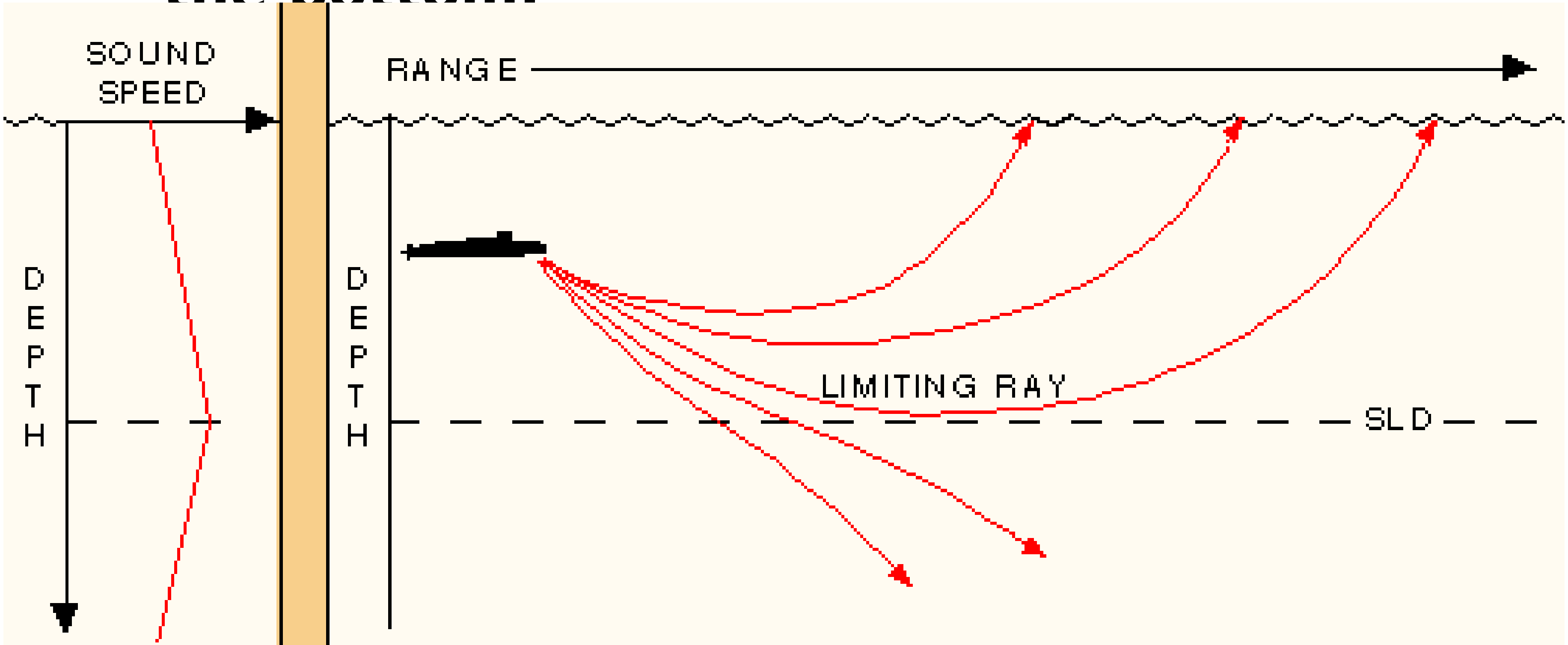
Source: RP-33

Basic Propagation Paths

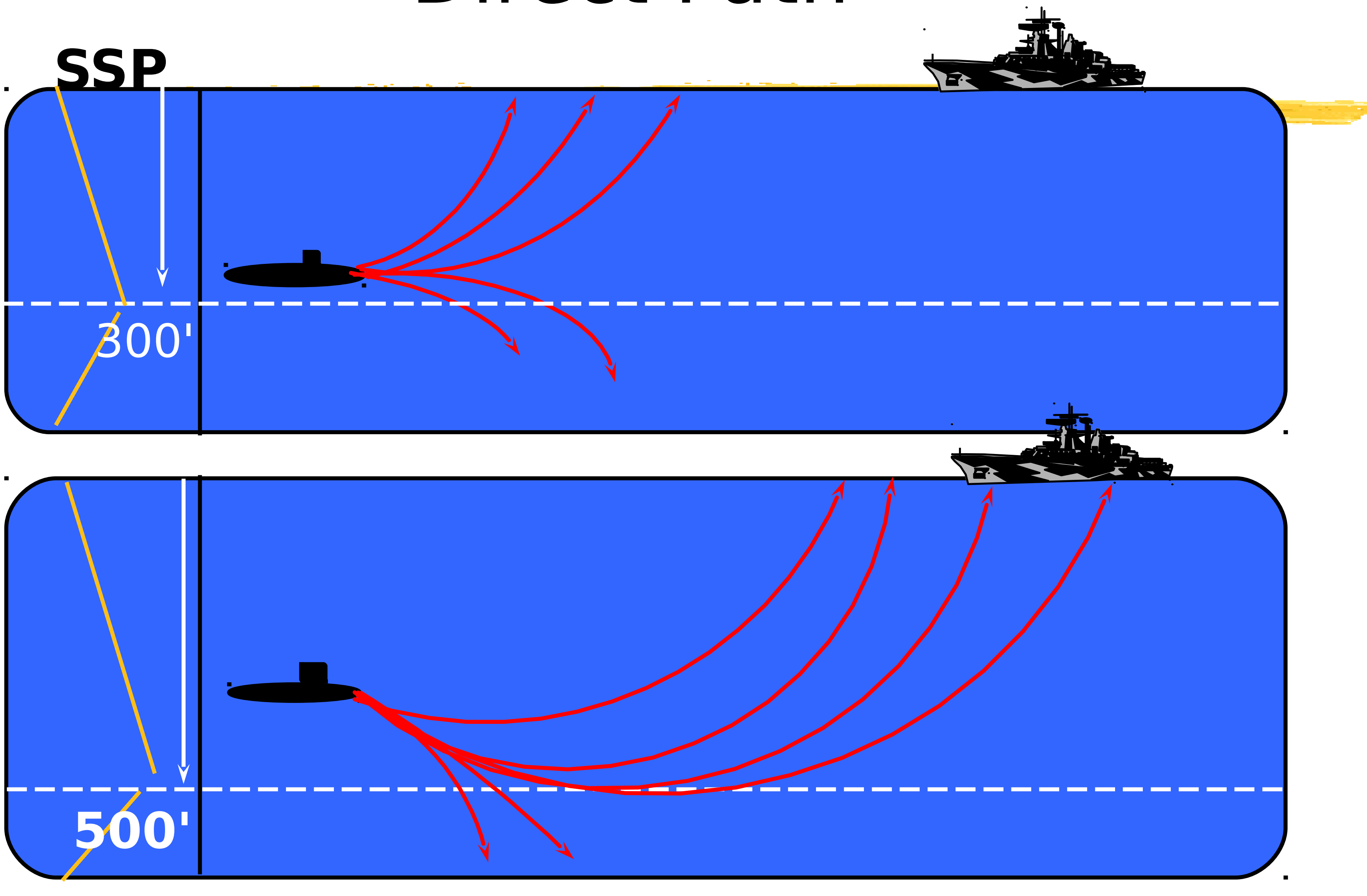
- **DIRECT PATH (1-8 kyds)**
- **SURFACE DUCT (10-30 kyds)**
- **BOTTOM BOUNCE (30 kyds)**
- **CONVERGENCE ZONE (60 kyds)**
- **SOUND CHANNELS (UNLIMITED)**

Direct Path

- **Short range path - includes only those ray paths from source to receiver with no interaction with the surface or the bottom.**

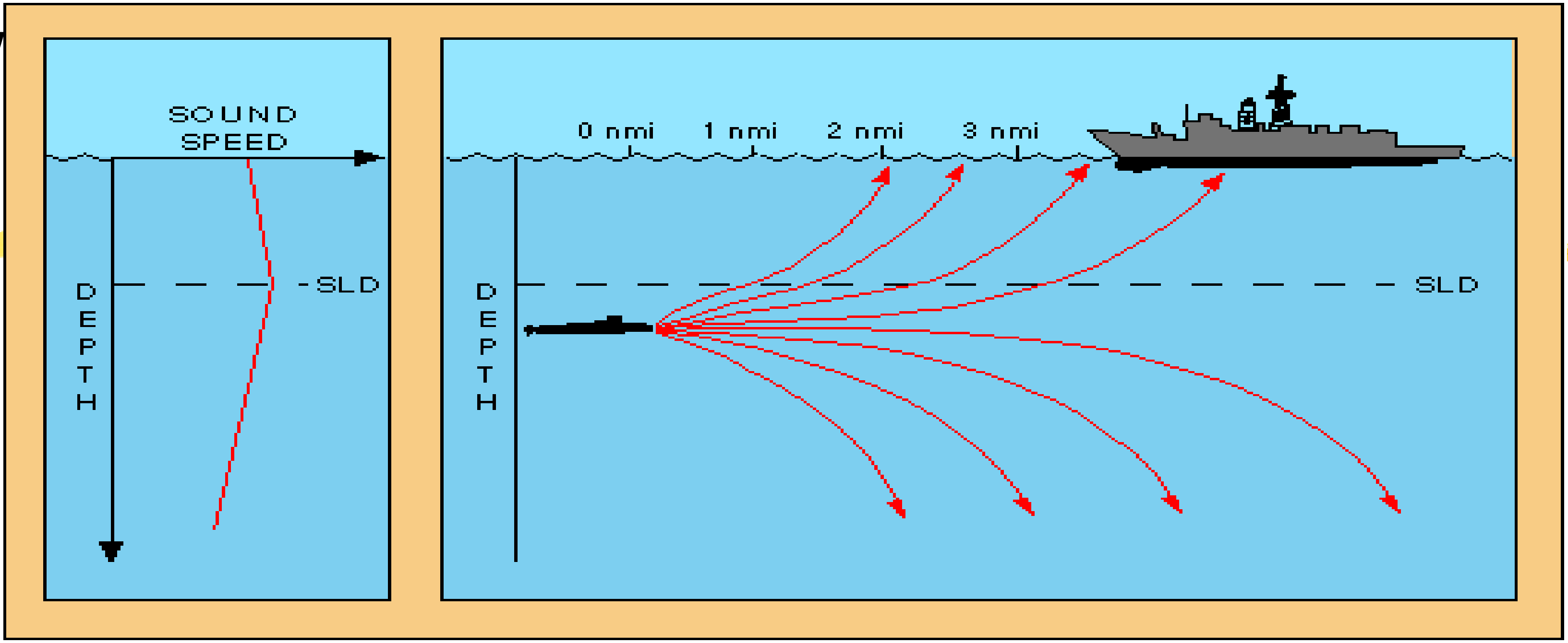


Direct Path



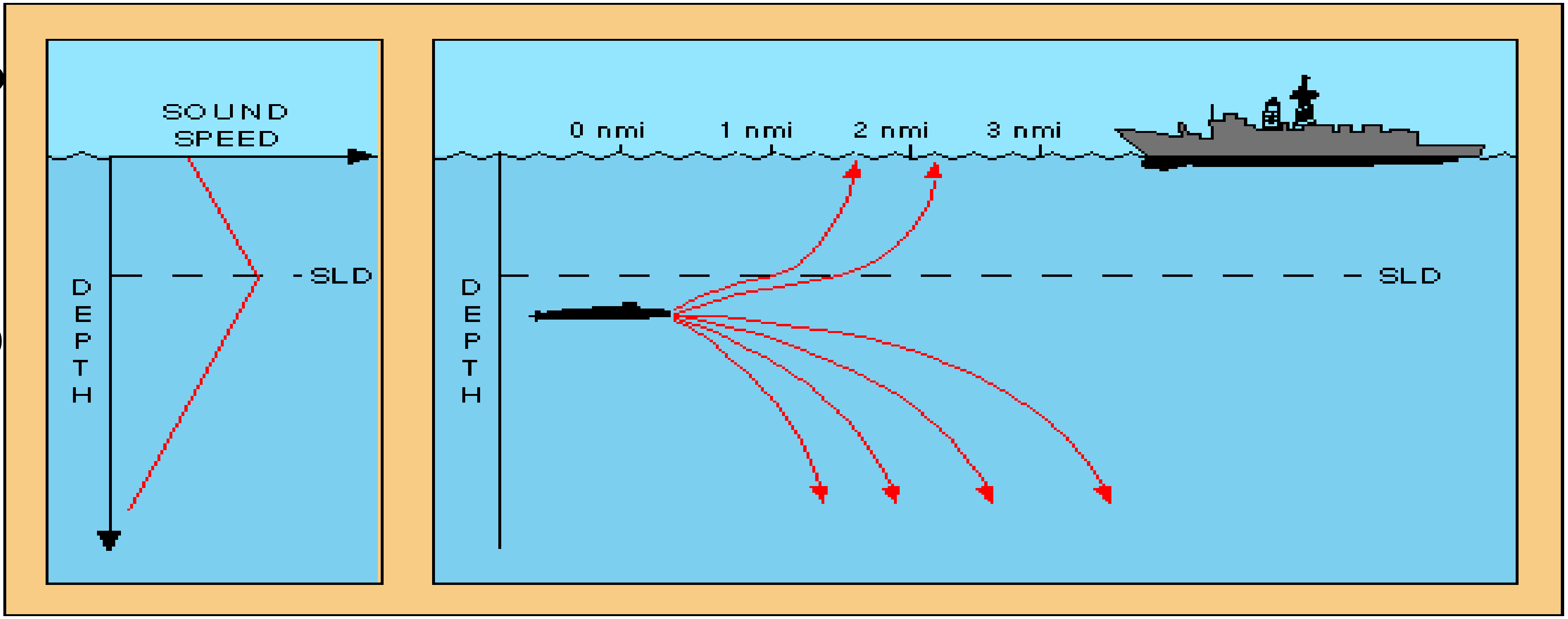
DIRECT PATH SOUND RAYS WITH WEAK NEGATIVE GRADIENT IN THE THERMOCLINE (SOURCE BELOW THE LAYER)

weak



DIRECT PATH SOUND RAYS WITH STRONG NEGATIVE GRADIENT IN THE THERMOCLINE (SOURCE BELOW THE LAYER)

Strong



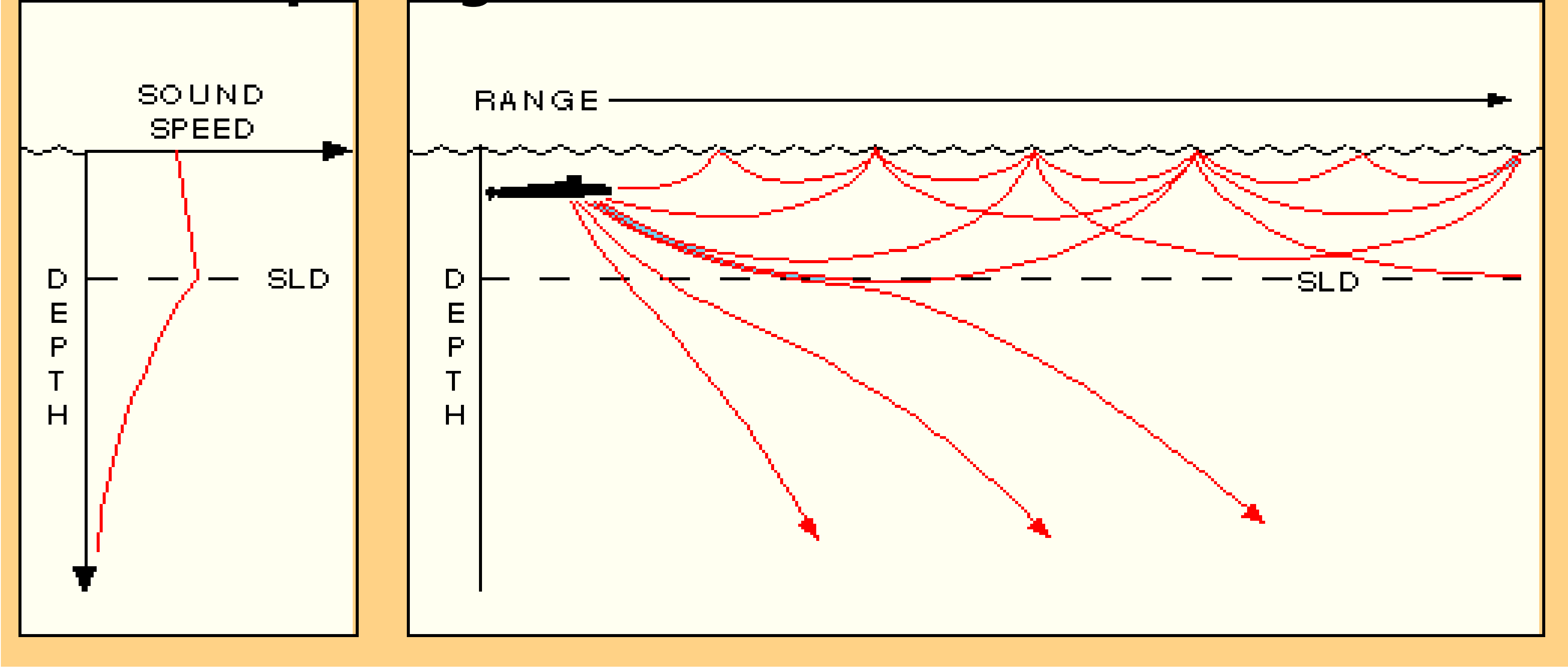
Direct Path Propagation Factors

- Sonic Layer Depth (SLD)
  - deep SLD: long direct path range
  - shallow SLD: short direct path range

- Sound Speed Gradient (SSG)
  - weak SSG: long direct path range
  - strong SSG: short direct path range

Surface Duct

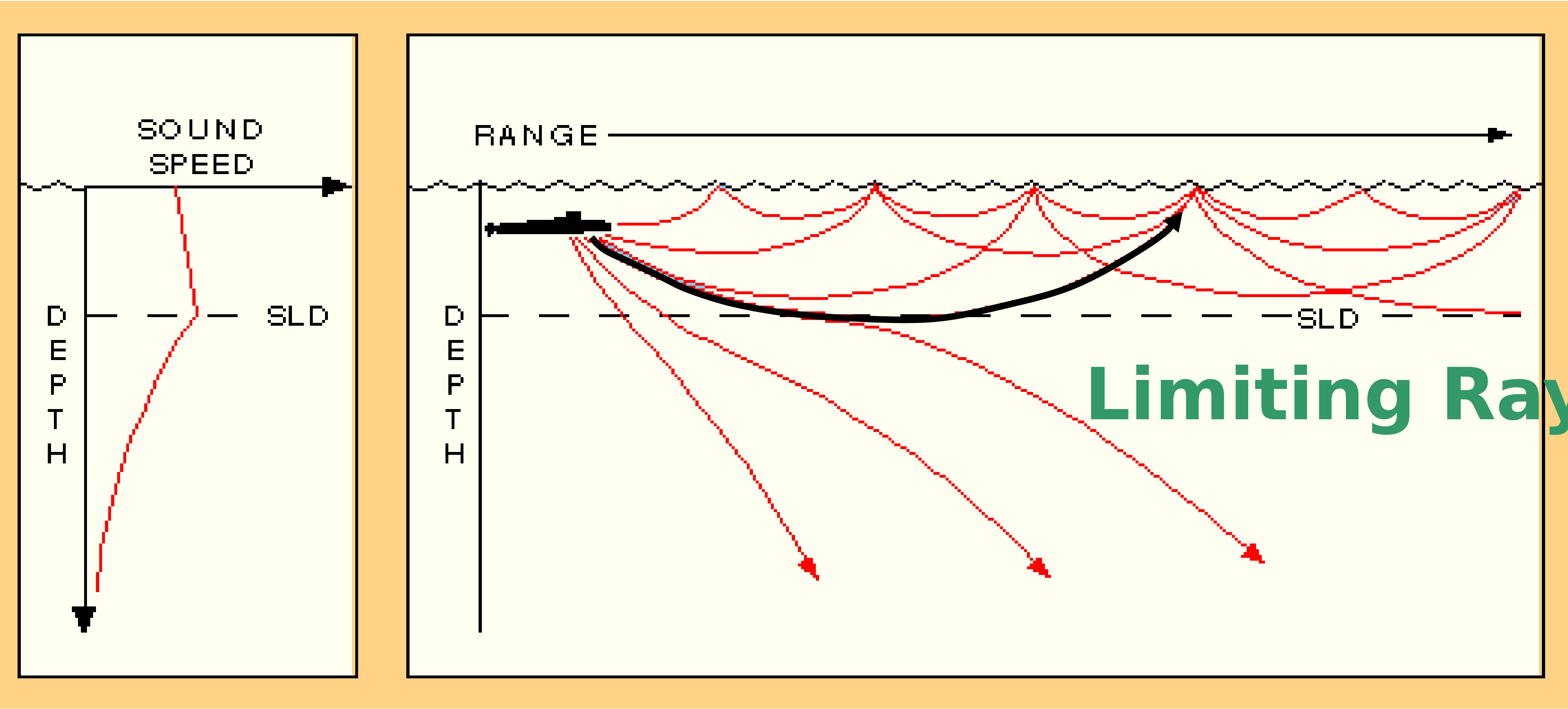
Trapping of sound rays in the mixed layer through repeated surface reflection and upward refraction due to the slightly positive sound speed gradient



Surface Duct

- Limiting Ray: The ray with a vertex speed equal to the maximum sound speed in the near surface layer.
  - **Defines the deepest ray that remains in the layer and the shallowest that escapes to the next layer.**
  - **All rays transmitted at greater angles escape.**
  - **All rays transmitted at lesser angles remain.**
  - **The depth at which the limiting ray reaches vertex speed is defined as the SLD.**

Surface Duct: Limiting Ray

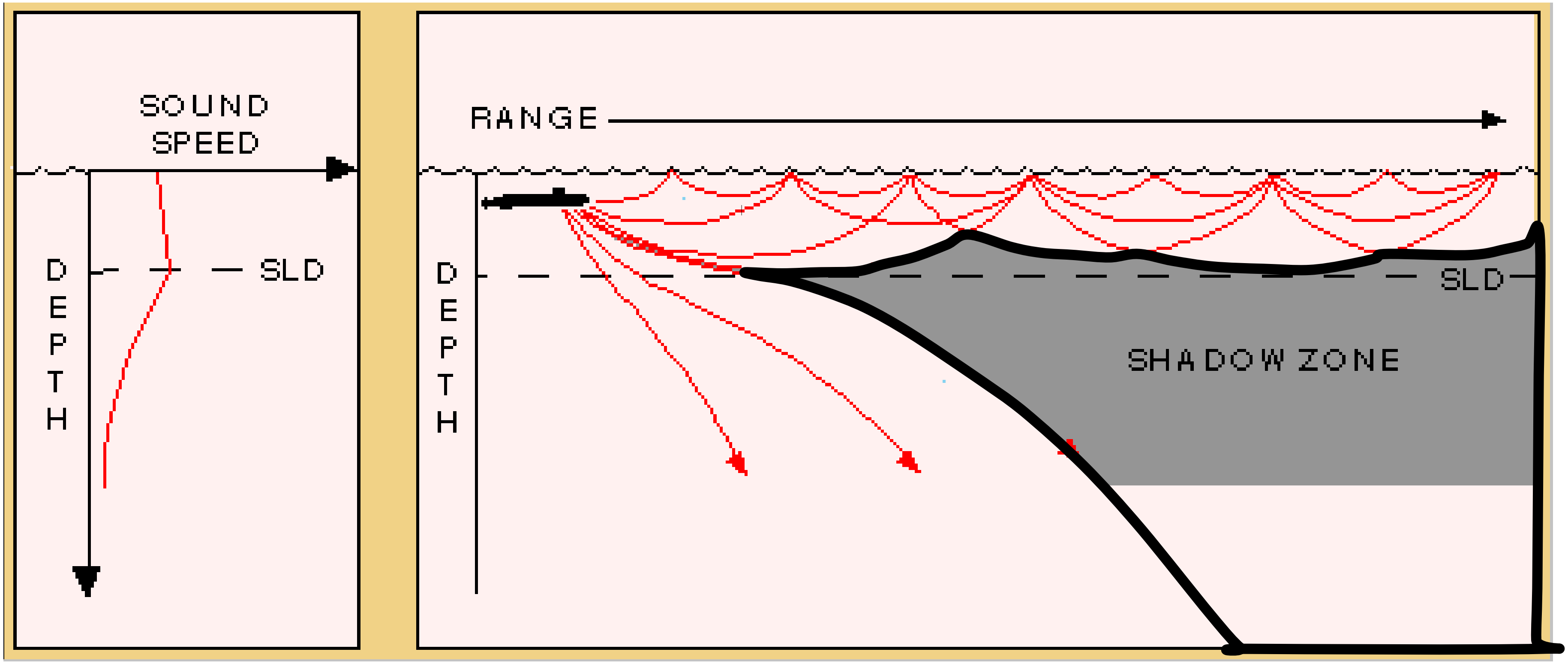


Surface Duct

Shadow Zone: An area of low sound intensity formed by the splitting of the limiting ray at the SLD.

- **Theoretically, no sound should enter the shadow zone, but some does due to scattering and diffraction.**
- **Sound intensity decreases exponentially with distance from the limiting ray.**

Surface Duct: Shadow Zone



Surface Duct Propagation Factors

- Sonic Layer Depth (SLD)
  - **Affects low frequency cutoff**
- Sound Speed Gradient (SSG)
  - **Steeper SSG's duct lower frequencies**
- Sea State
  - **Scattering loss increases with sea state**
- Transmission Angle
  - **Steeper angles are not ducted**

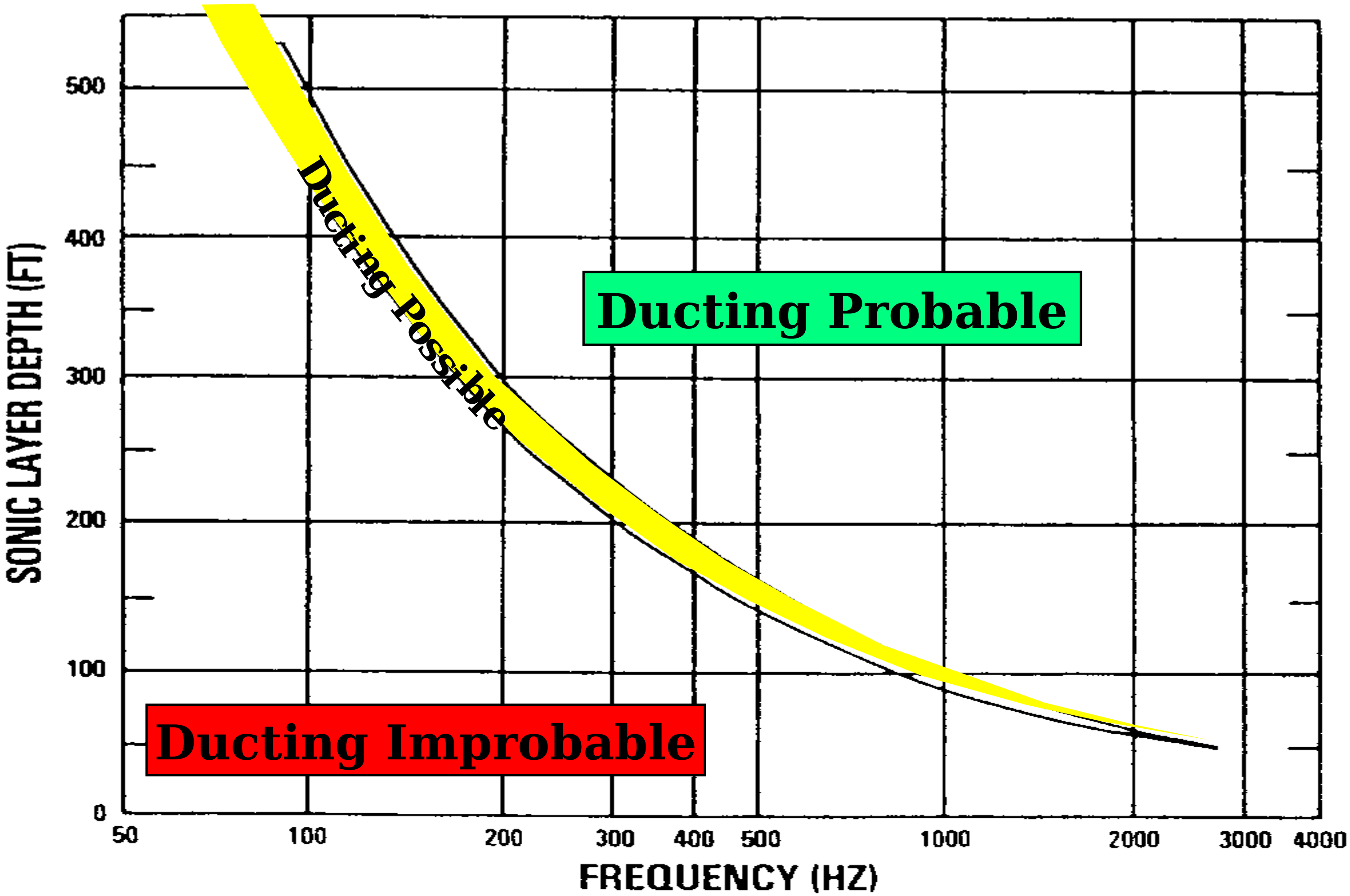
Surface Duct
Low Frequency Cutoff

The layer is equivalent to a waveguide:

- as frequency decreases, wavelength becomes too large to fit in the layer and does not duct

- frequencies below the low frequency cutoff will be refracted into the deep sound channel

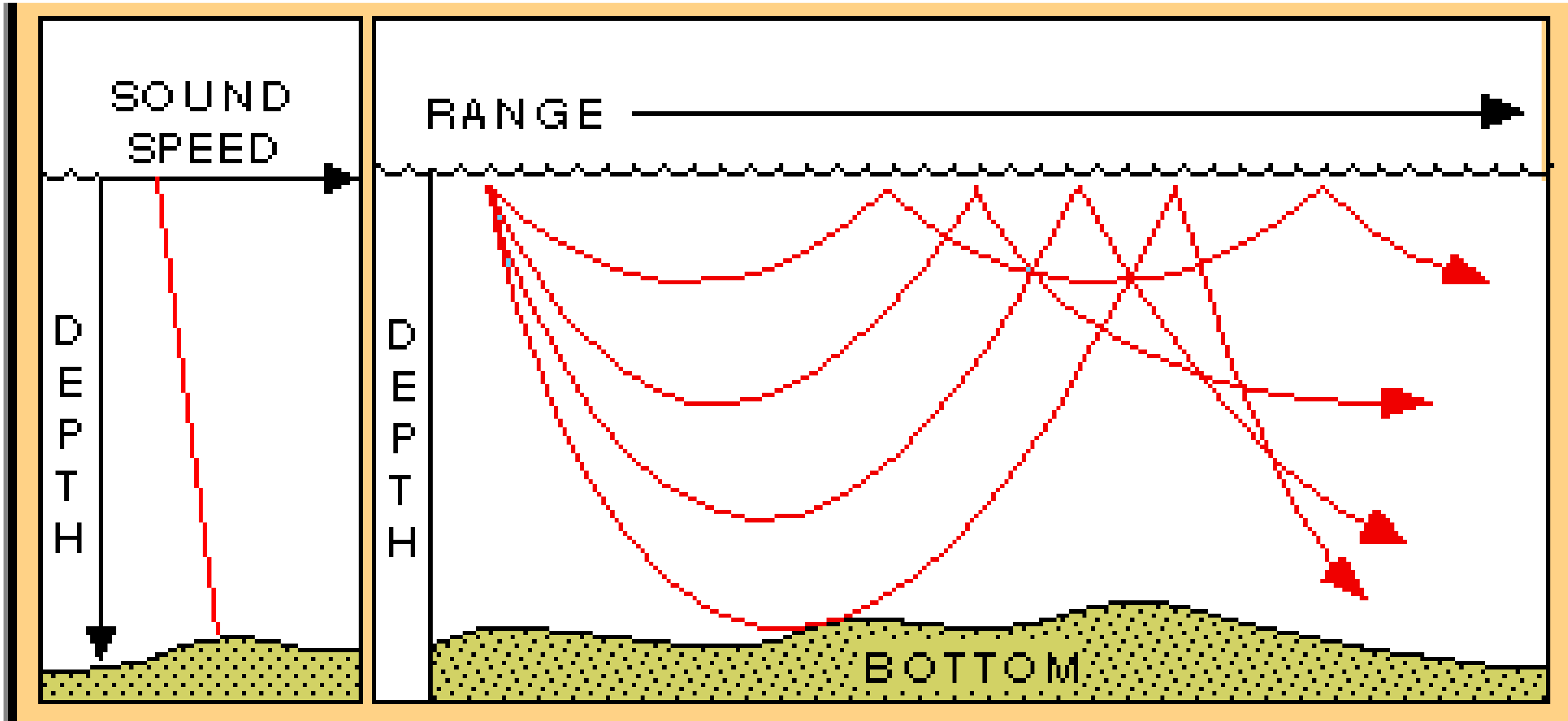
Surface Duct Cutoff Frequency (f_c)



Source: RP-33

Half Channel

Special case of surface duct propagation such that a positive sound speed gradient extends from the surface to the bottom

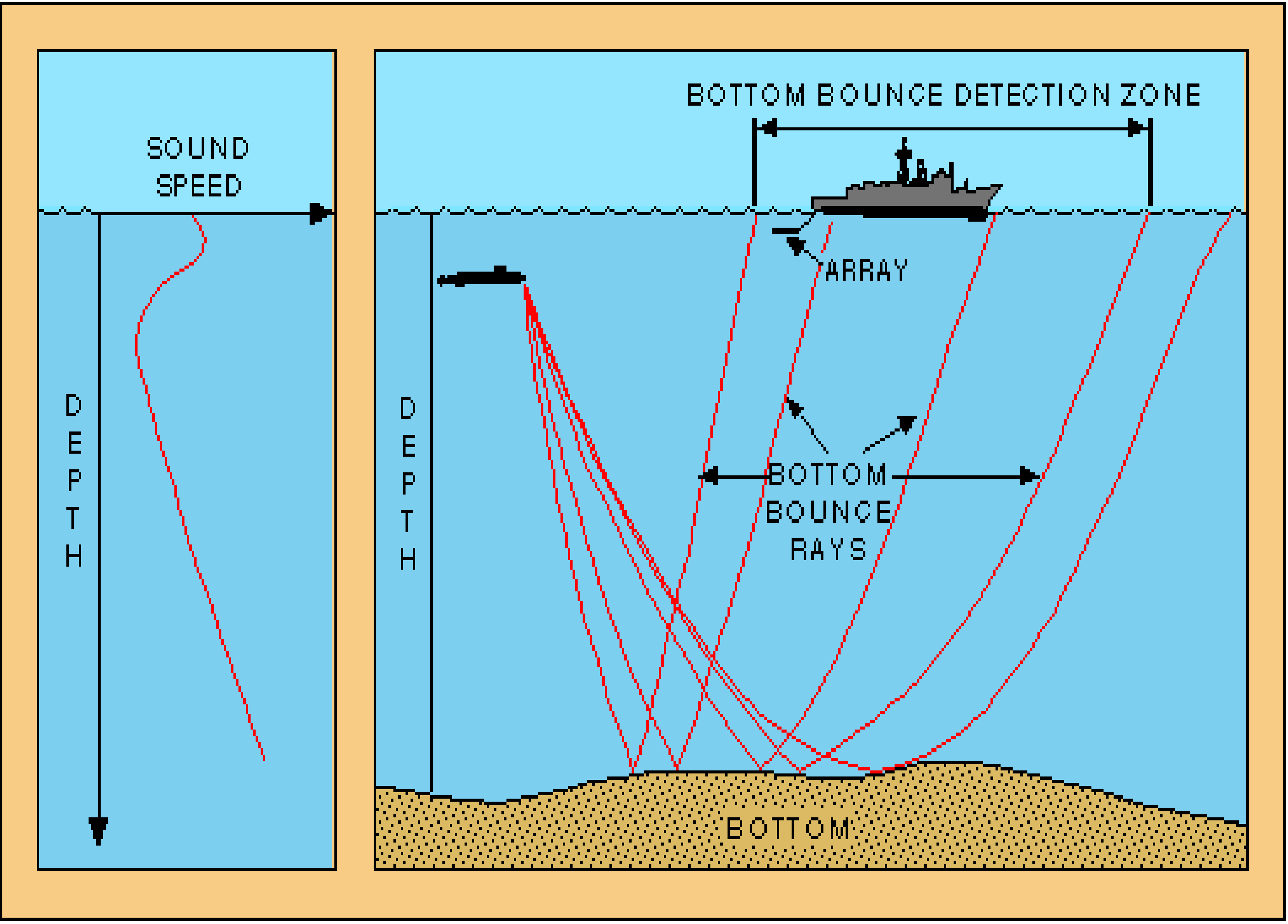


Bottom Bounce

- Definition: Indirect bottom-reflected path used by all active/passive sonars.

- Relatively independent of temperature and speed gradients due to steep angle of transmission.

BOTTOM BOUNCE



Bottom Bounce

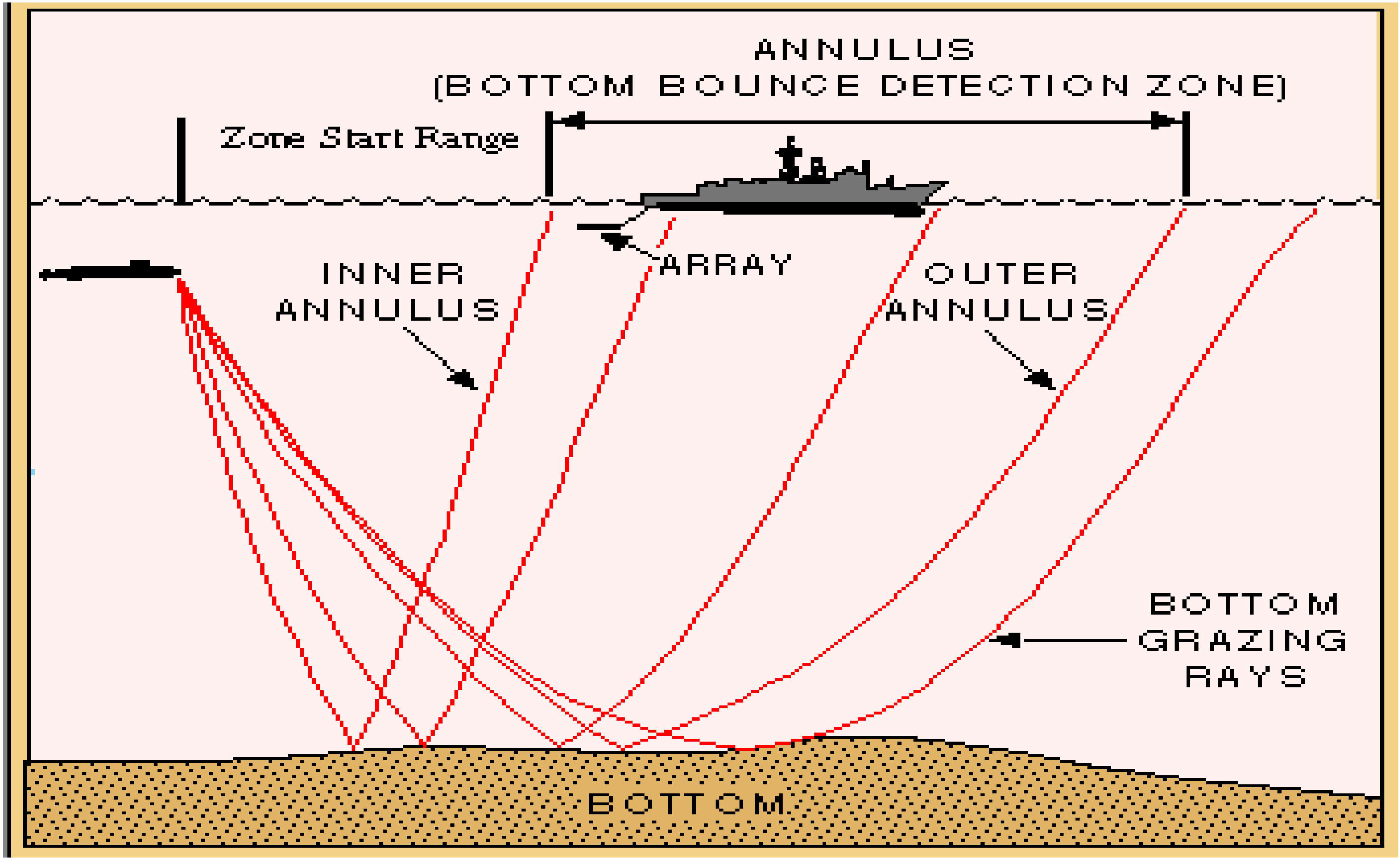
- Always available, not always exploitable.
- Enhanced when source is in strong negative gradient.

Bottom Bounce

BB path components:

- **Annulus:** The area of ensonification at the surface.
- **Zone start range:** Horizontal range from source to where zone of ensonification begins.

Bottom Bounce



Bottom Bounce Propagation Factors

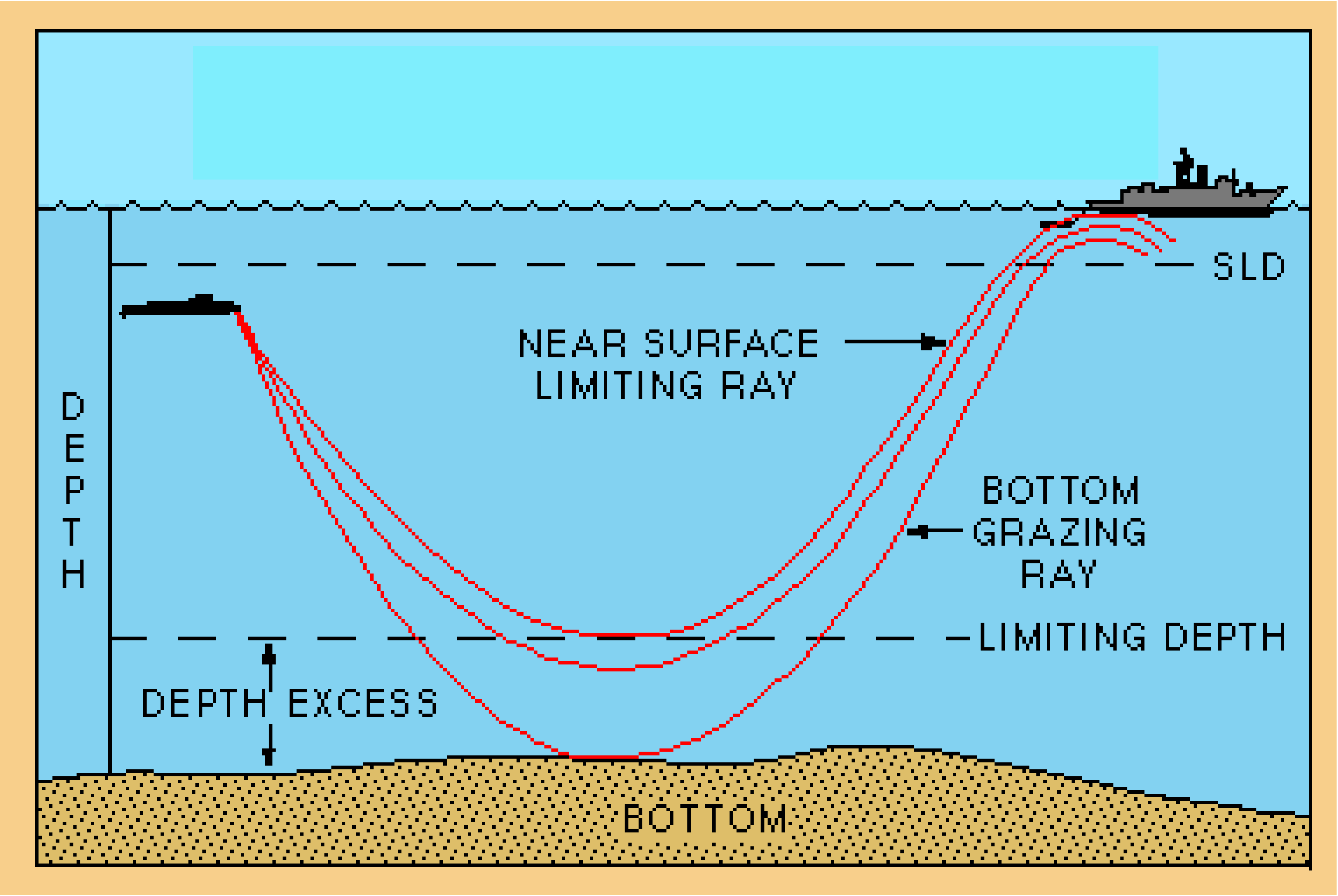
- Water depth
- Angle of incidence/bottom slope
- Frequency
- Bottom composition
- Bottom roughness
- Sea State

Convergence Zone

- Surface or near surface regions where “focusing” of sound rays of occur, resulting in high sound levels.

- Formed when sound is refracted downward and then back up to the surface.

Convergence Zone



Convergence Zone

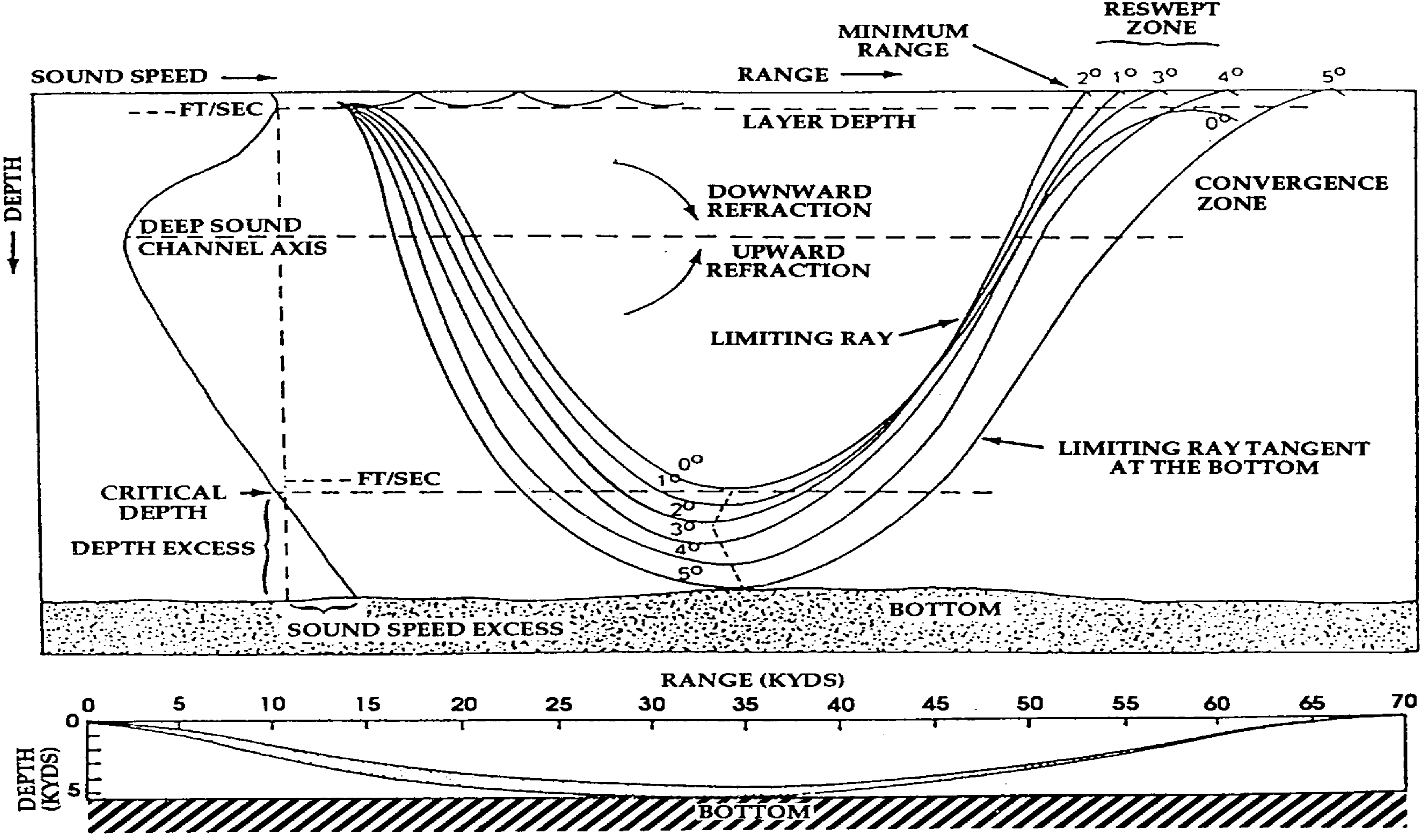
- Annulus - The area of increase sound intensity at the air/sea interface.
- Critical Depth - The depth where the SLD sound speed value is repeated below the deep sound channel axis.
- Depth Excess - The difference between bottom depth and critical depth.

Convergence Zone

- Sound Speed Excess - The difference between sound speed at the bottom and sound speed at critical depth.

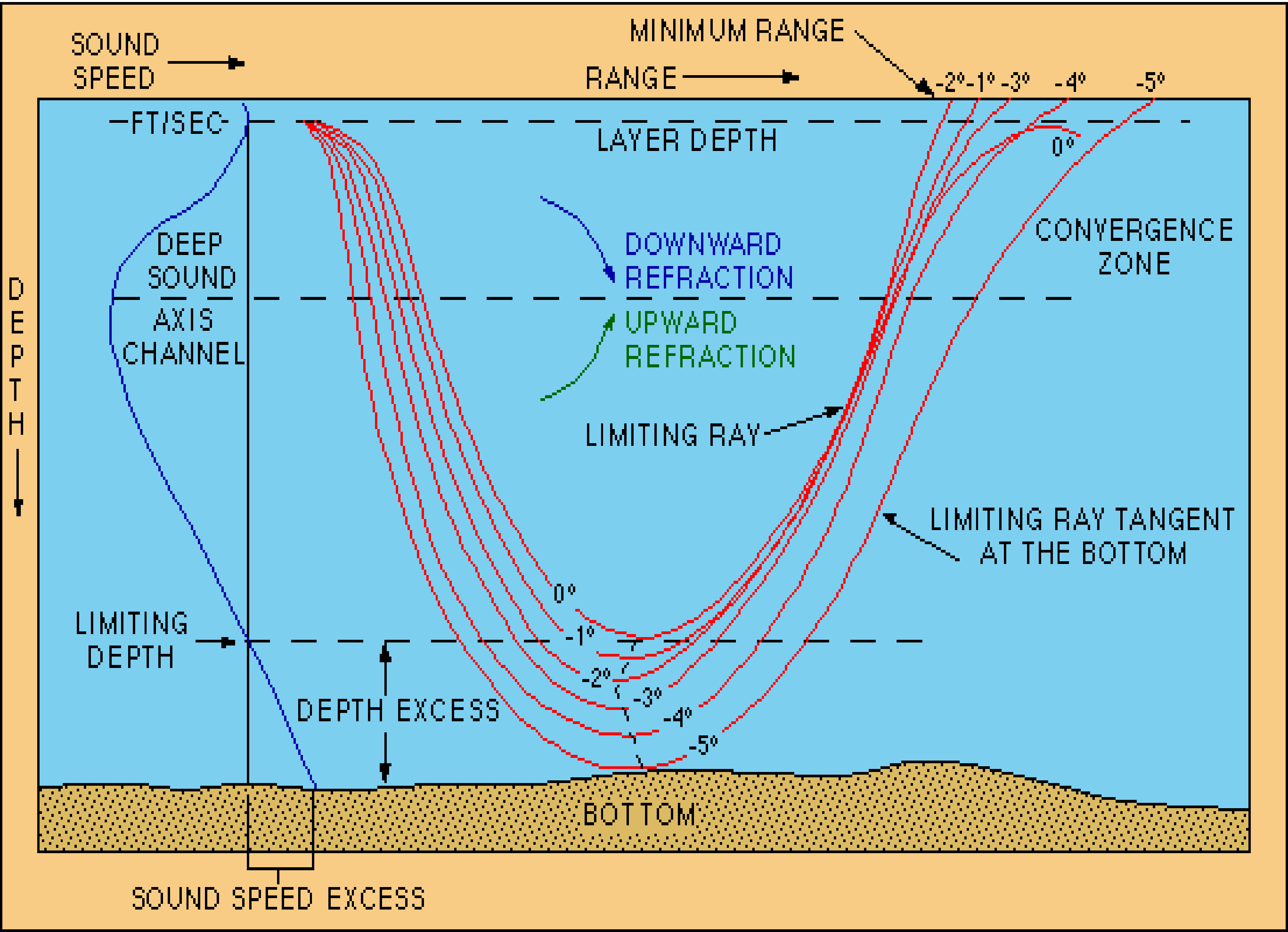
- Conjugate Depth - The depth where the sound speed at the target's depth is repeated below the DSCA.

Convergence Zone



Source: RP-33

COMMON DEPICTION OF A CONVERGENCE ZONE



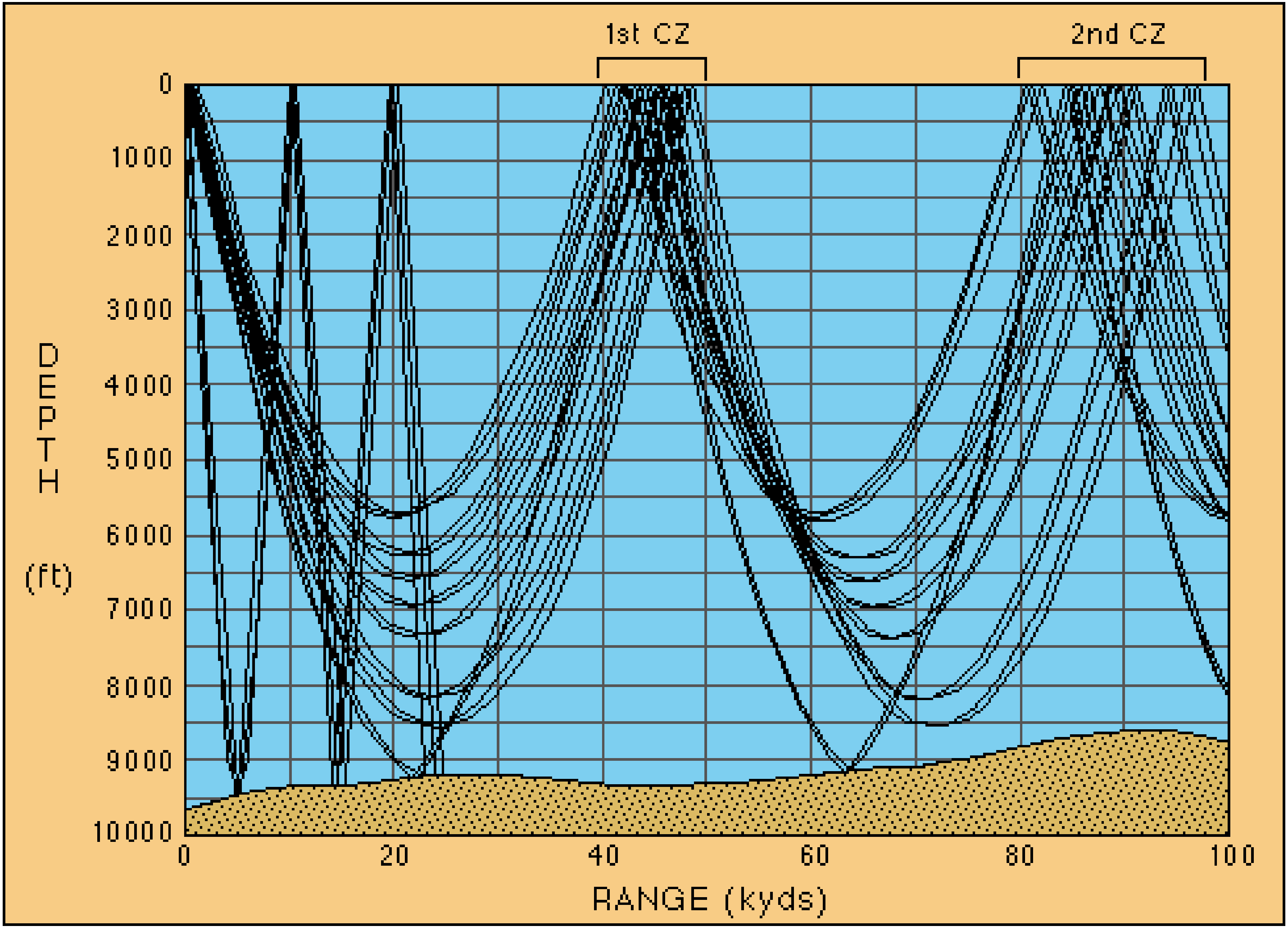
CZ & Annulus Range/Width

- Width of annulus varies with depth excess. As depth excess increases, the annulus widens.
  - **Rule of thumb for annulus width???**

10 percent of the range

- Range to annulus varies with sea surface temperature. As SST increases, annulus ranges increase.

FIRST AND SECOND CZ



CZ & Critical Depth/Depth Excess

- If water depth is less than critical depth, no CZ can exist.
- **200** fathoms of depth excess provides probability that CZ will occur.
- **300** fathoms of depth excess provides probability that CZ will occur.

CZ & Sound Speed Excess

- **22** ’ ft/sec of sound speed excess provides 50% probability that CZ will occur.

- **30** ’ ft/sec of sound speed excess provides 80% probability that CZ will occur.

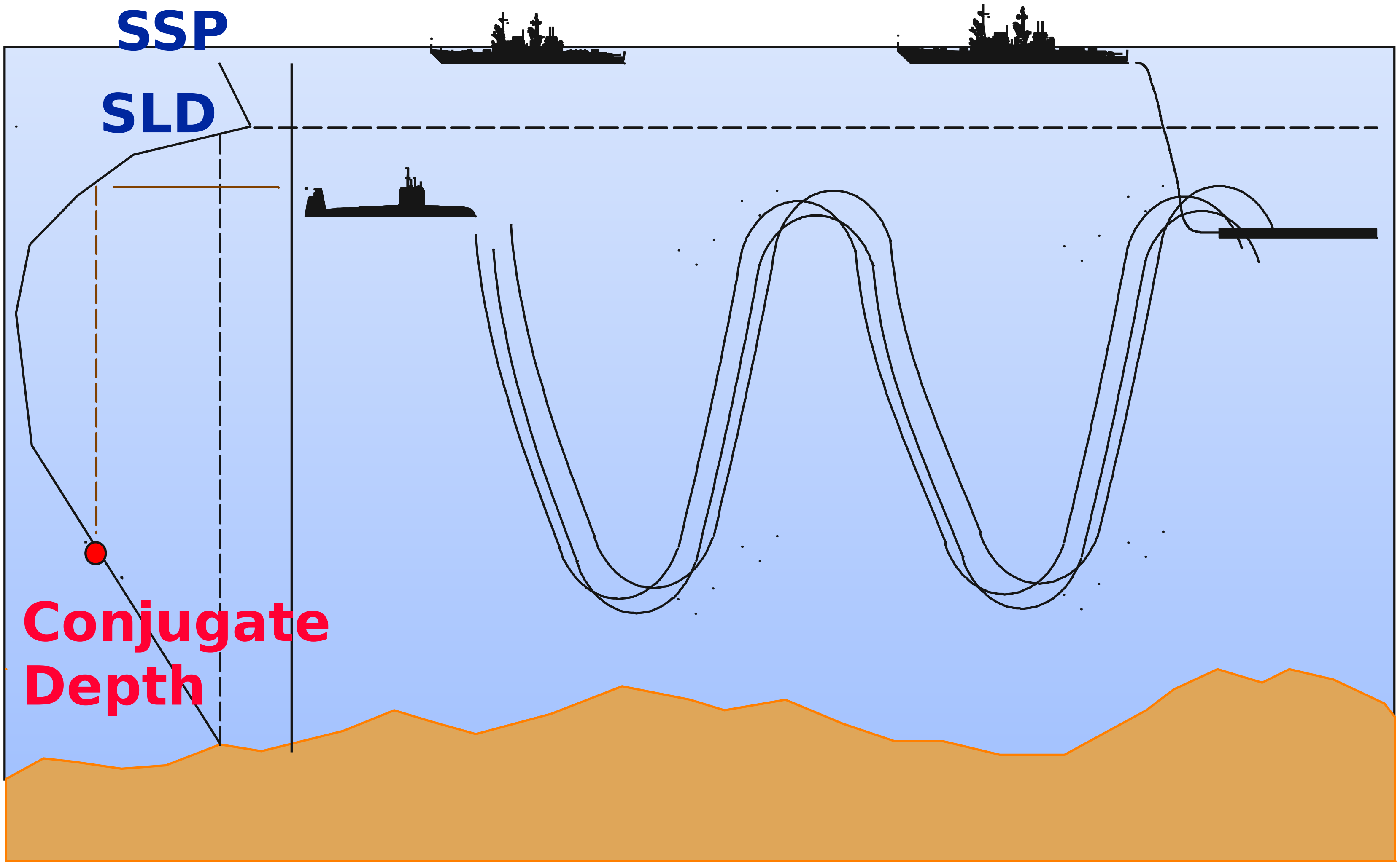
CZ Propagation Factors

- SSP
- Water Depth (Critical depth, Limiting depth, Conjugate depth all of which relate to Depth Excess)

CZ Propagation Factors

- Sea State
  - Increased sea state degrades multiple CZ’s
  - Max wind speed about 20 kts for usable CZ
- Bottom Topography
  - Topographic Shading

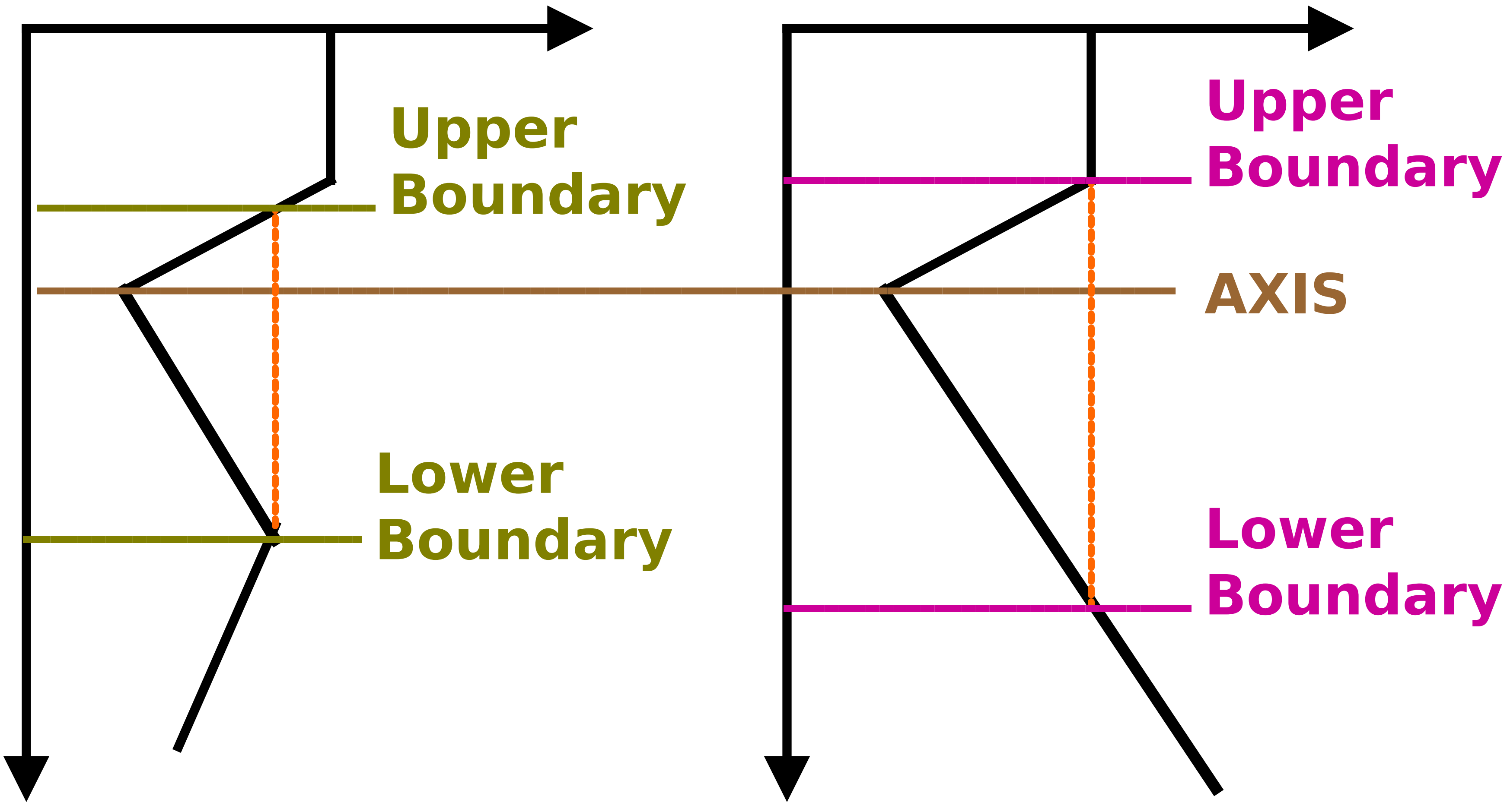
Submerged CZ



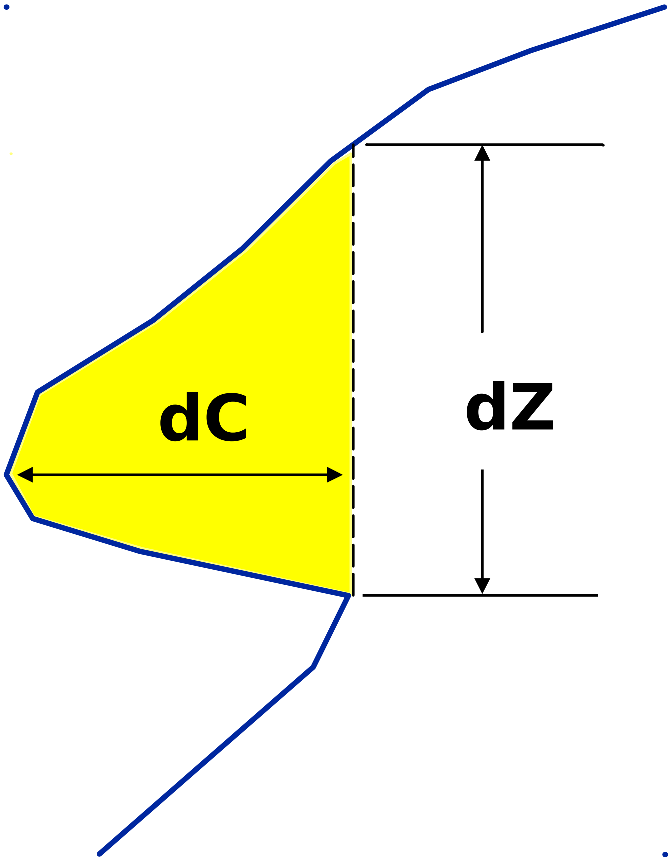
Sound Channels

- A region in the water column where sound speed first decreases with depth to a minimum value, then increases with depth
  - Requires a negative over a positive gradient
  - Sound becomes trapped in sound channels and can travel extreme distances

Sound Channels



Sound Channels



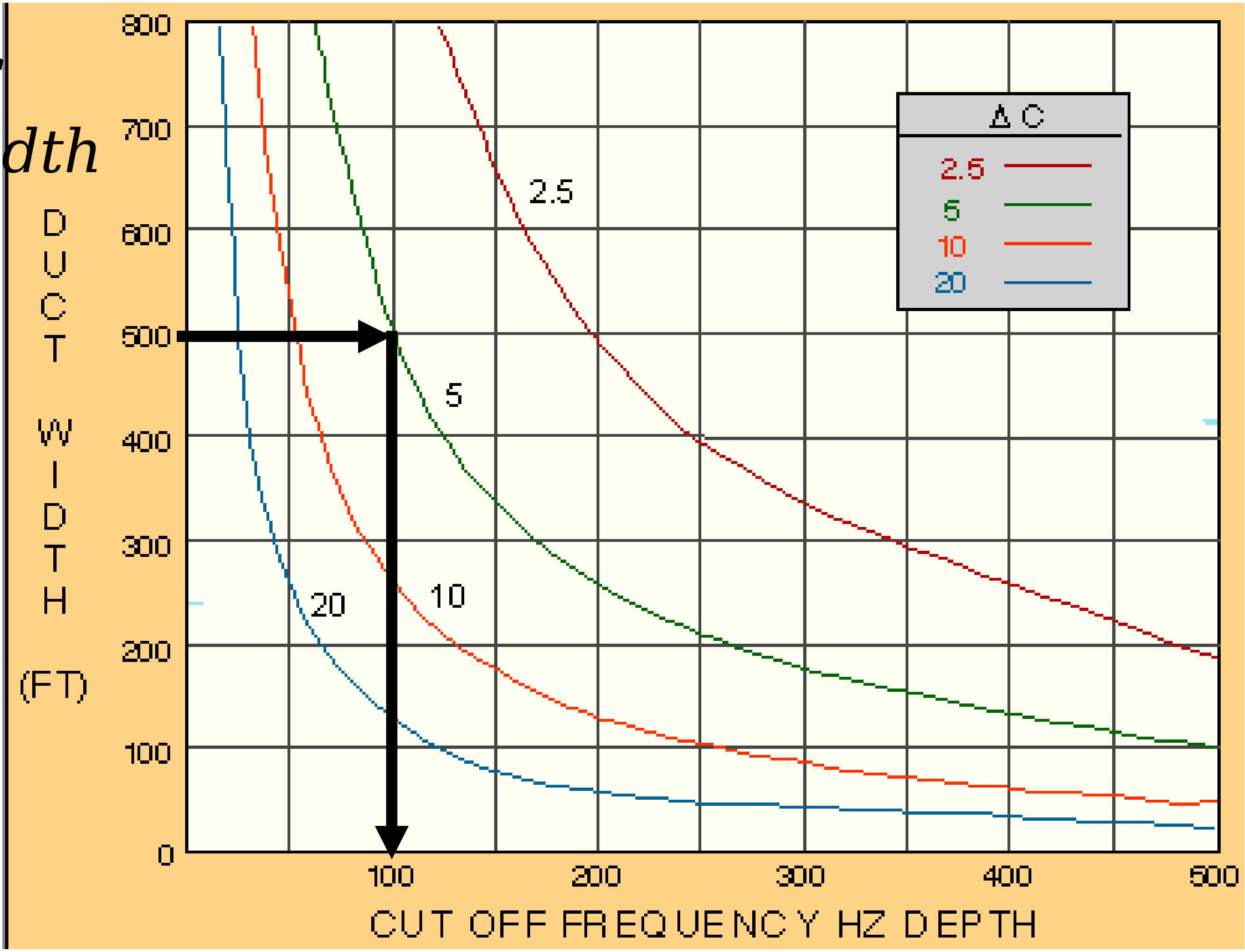
dC = Strength: change in soundspeed from min to max

dZ = Width: vertical extent from upper to lower boundary

Sound Channel
Low Frequency Cutoff

LFC for a SSC with a duct width of 500 ft and strength 5ft/s

100 hz



Sound Channels

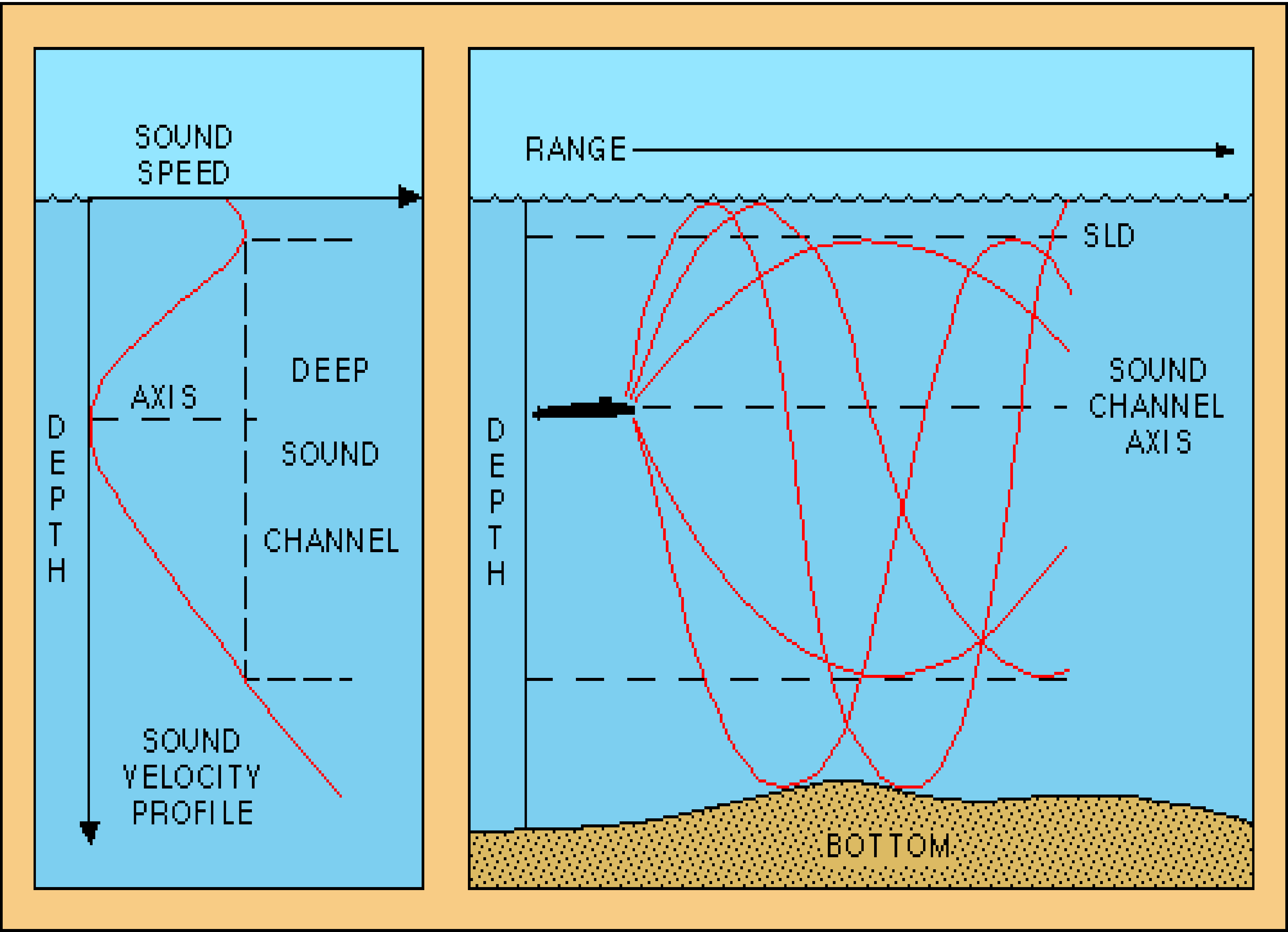
Two types of sound channels:

- **Deep Sound Channel (DSC)**
- **Shallow/Secondary Sound Channel**

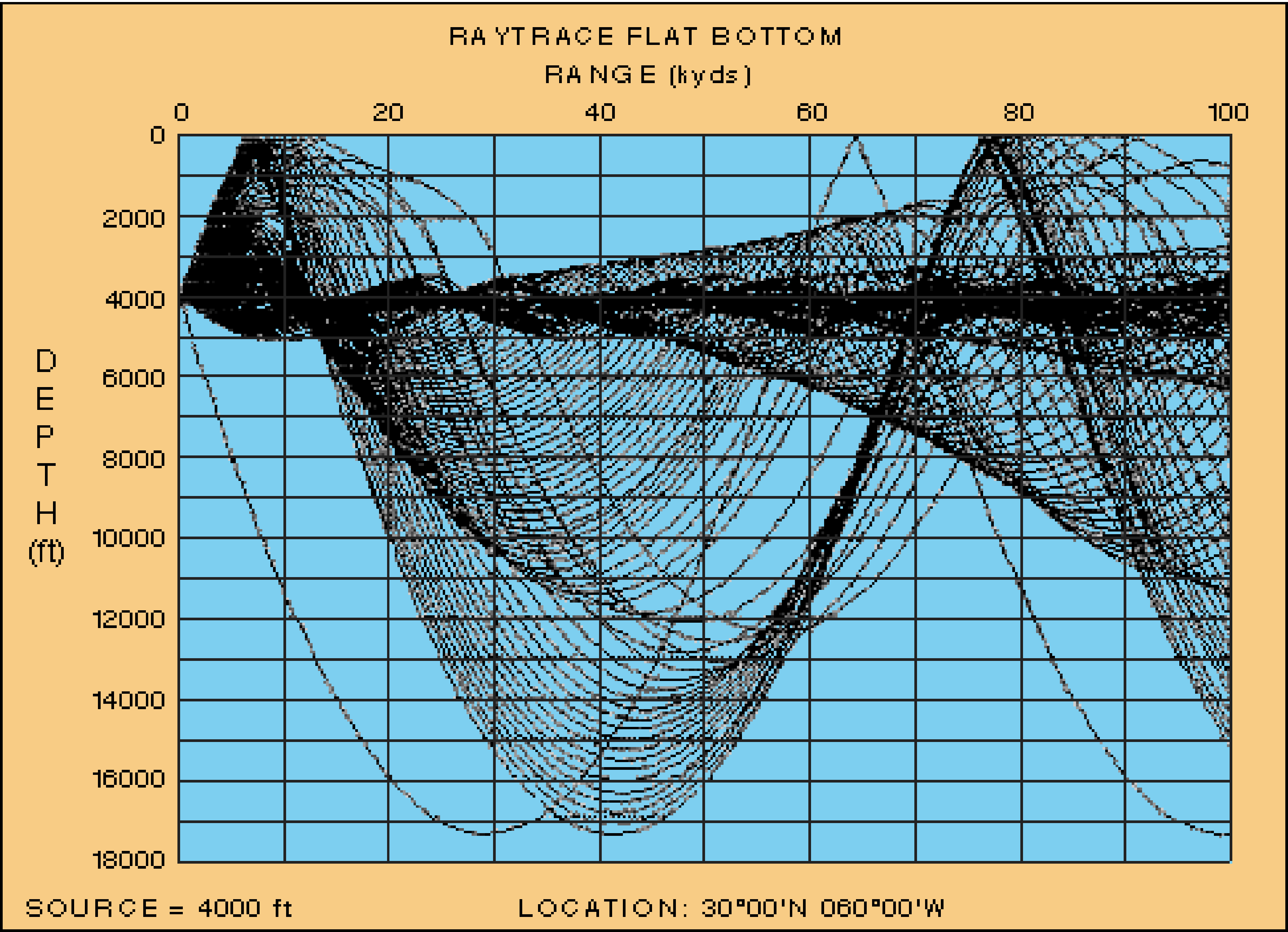
Deep Sound Channel

- **Permanent feature of the deep ocean**
- **Axis varies between 4000 ft (mid-latitude) to near the surface (polar regions)**
- **Produces the longest ranges possible in the oceans**

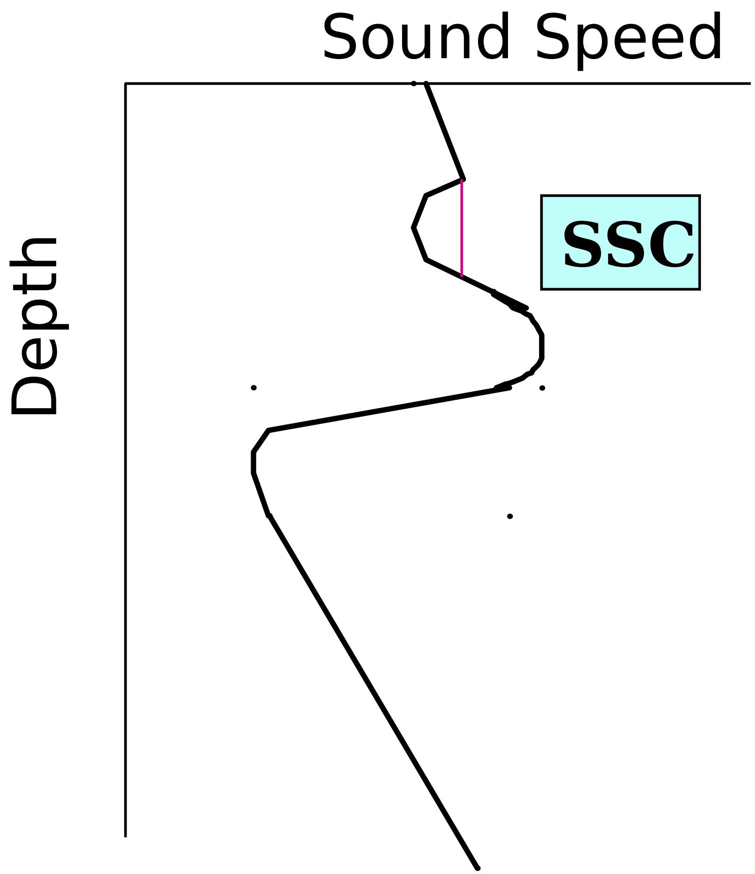
DEEP SOUND CHANNEL



THREE-DIMENSIONAL RAY DIAGRAM OF A SOUND CHANNEL



Shallow/Secondary Sound Channel



- Occurs in the upper levels of the water column
- Prevalent depths 300 to 500 ft
- Transitory features, often associated with fronts and eddies